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CONDITIONED FLEXION RESPONSES IN DOGS RE-ESTABLISHED AND MAINTAINED WITH CHANGE OF LOCUS IN THE APPLICATION OF THE UNCONDITIONED STIMULUS

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INTRODUCTION

The present investigation was designed to test the following hypothesis: if the left forelimb flexion-response of dogs to shock is conditioned and then extinguished, will the same CS[2] evoke the extinguished CR, if the shock when it is again paired with the CS is applied to a new locus, and if the extinguished CR is alone instrumental in the avoidance of shock? Electric shock when applied at a new locus, *e.g.*, the right forelimb, is the US for right forelimb flexion, an UR. Pairing of this shock with a CS would result undoubtedly in the conditioning of right forelimb flexion in a naïve subject. But will this happen when left forelimb flexion has been first conditioned and extinguished, particularly when conditioned left forelimb flexion to the CS brings an avoidance of the shock in its new locus?

Kellogg and Walker (7, 8), using dogs as subjects, conditioned the right forelimb flexion-response, evoked by shock,

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[2] Abbreviations: US = Unconditioned (original) Stimulus; UR = Unconditioned (original) Response to US; CS = Conditioned (substitute) Stimulus; and CR = Conditioned Response.

to the sound of a buzzer. This response was then extinguished and reconditioned, whereupon the shock was transferred to the *left* forepaw. Under the latter condition, when the buzzer was followed by shock to the left forepaw, right forelimb flexion-responses were elicited by the buzzer. The introduction of the left foot shock served at the start to facilitate conditioned right forelimb flexion-responses, in the case of all six of the subjects. Three of the animals rapidly adapted to the change in the situation by eliminating the right foot response altogether and by giving only left foot flexion-responses to the CS. With the other three animals, the frequency of conditioned right forelimb flexions to the buzzer did not diminish during the time in which left forelimb flexion was conditioned to the criterial level. Thus, the buzzer evoked conditioned flexions of both the right and left forelimbs, a phenomenon which Kellogg and Walker have called 'ambiguous conditioning.'

Finch and Culler (4) have pointed out that the US performs a dual role in the conditioning process. First, it determines the character or pattern of response. Right forelimb flexion from an electrically-charged grid is clearly a function of the type of stimulus (electric shock) and also of its locus of application (right forepaw). The CS takes over this function of the US only, that of evoking a definite behavior-pattern. Secondly, the US provides the incentive or drive needed to actuate this response. Dogs conditioned to forelimb flexion by these authors required a mean time of 14.9 periods for extinction when a buzzer (which during training sounded for the exact duration of the electric shock) was present and 4 periods when it was absent. The buzzer was neither an US nor a CS for flexion; at no time was it possible to evoke forelimb flexion to the buzzer sounded alone. The buzzer had for a time taken over the second function of the US, that of providing the incentive or drive for response.

While in the experiment of Finch and Culler the buzzer did not effectively take the place of shock in maintaining a consistent flexion-response to the CS, Brogden (2) has reported an experiment in which a neutral stimulus provided an

effective substitute for the US in consistently maintaining flexion-responses to the CS. With dogs as subjects, once left forelimb flexion, evoked by shock, had been conditioned to the ringing of a bell, each CR thereafter was rewarded by a biscuit dropped into a food-box, shock being omitted altogether from the test-situation. If no CR was made to the CS, no food was delivered. Under these conditions of reinforcement, the experimental animals gave a mean CR-frequency of 97.7 percent during 1000 trials, while the control animals, maintained with shock, gave a mean CR-frequency during the same period of 98.8 percent. Food was neither an US nor a CS for flexion; at no time was it possible to elicit forelimb flexion when the food was presented alone. Food, then, functioned as well as shock in providing the incentive needed to actuate the CR.

The analysis which Finch and Culler have made of the dual functioning of the US, and the evidence which they and Brogden have presented in its support, lend credence to the hypothesis which was presented at the beginning of this paper. In addition, when we recall the statement of Kellogg and Walker, that in their experiment, the change of shock from the right forepaw to the left forepaw served at first to facilitate CR's of the right forelimb, the hypothesis receives further support. The hypothesis which is to be subjected to experimental interrogation then, is as follows: when left forelimb flexion-responses to shock have been conditioned and extinguished, if shock is applied at another locus, will the old response be re-established and maintained, when it alone is instrumental in shock-avoidance?

Experimental Procedure

Twenty mongrel dogs, secured from an unselected laboratory stock, and naïve with regard to all conditioning experiments served as subjects in this investigation. The animals were placed in a stock within a light-shielded sound-proofed test-chamber with a one-way glass screen through which the experimenter made his observations. Once in the stock, the wrist of each of the animal's limbs was attached by means of a strap to a lever, which permitted vertical flexion of the extremity thus restrained. With all animals, left forelimb flexion, evoked by shock, was conditioned to the ringing of a bell. The shock circuit was automatically broken whenever flexion occurred, so that a CR was rewarded by shock-avoidance. The stimuli were electrically controlled by a telechron motor which made each stimulus-sequence identical. The bell was 2 seconds in duration and was followed immediately by shock which lasted for 1/10 of a second.

Twenty trials per day were given as the test-unit. When 100 percent conditioned flexion to bell was reached (20 shock-avoiding flexions to 20 presentations of the bell in one test-period), the twenty animals were divided at random into 5 groups of four animals each. In re-establishing conditioned left fore-limb flexion to bell, shock was applied at the following loci: right forelimb (Group I); right hindlimb (Group II); left hindlimb (Group III); right thorax (Group IV); and left forelimb (Group V—controls). Shock when applied at these loci produced flexions of the limbs, and at the right thorax, a sudden inspiration and curving of the trunk toward the left. When left forelimb flexion had been re-established to the 100 percent response-criterion, these experimental conditions were maintained for an additional 5 test-periods (100 trials) for each group. The intensity of the electric shock, whenever and wherever it was applied, was adjusted to that magnitude which just elicited an easily observable response.

With this procedure then, the efficiency of 5 different loci of shock in re-establishing and maintaining conditioned left forelimb flexion can be demonstrated by comparing the data obtained from the 4 experimental groups with that obtained from the control group.

Once this data had been obtained, the animals of Groups I, II, and III were treated in a manner such that their behavior might be compared with that of the dogs which were used as subjects in the experiments of Kellogg and Walker (7, 8). These authors conditioned right forelimb flexion in six dogs, extinguished and reconditioned this response, and then transferred shock to the *left* forepaw, observing the extinction of the right forelimb and the conditioning of the left forelimb, until the latter response had been conditioned to the criterion. Since in the present experiment, left forelimb flexion had been originally conditioned, extinguished, and then reconditioned (with change in shock-locus), the effective transfer situation occurs when flexion of the limb where shock has its new locus is made instrumental in shock-avoidance, rather than left forelimb flexion. The two experiments then become fairly similar in procedure and thus permit comparison of results.

With the animals of these groups then, shock was still applied to the new locus (Group I—right forepaw; Group II—right hindpaw; Group III—left hindpaw), but instead of conditioned left forelimb flexion resulting in shock-avoidance, shock followed every response to bell except the one which it evoked as a UR (Group I—right forelimb flexion; Group II—right hindlimb flexion; Group III—left hindlimb flexion). When these flexions reached the 100 percent CR-criterion, the bell was presented alone until the extinction criterion was attained. Then the shock was transferred to the *left* forepaw, and CR's of either the left forelimb or the right forelimb (Group I only), of the right hindlimb (Group II only), of the left hindlimb (Group III only) resulted in shock avoidance. This condition was continued until conditioned shock-avoidance reached the 100 percent response-level. This score was attained when all the shocks presented in one test-period were avoided, it making no difference whether by flexion of the left forelimb or by flexion of the other appropriate limb.

Quantitative Results

Except for two cases in which left forelimb flexion could not be reconditioned to the criterial level, conditioned left forelimb flexion was re-established as rapidly and maintained at the same response-level when shock was applied elsewhere as when it was applied directly to the left forepaw. The data for all animals and for each group are given in Table I.

TABLE I

The CR scores for each animal are in percent left forelimb flexion-response to the 20 presentations of the CS given each test-period. The upper portion of the table gives the reconditioning results, while the lower portion gives the response-levels once conditioned left forelimb flexion has been re-established to the criterion. The mean number of test-periods required to attain the criterial performance is given for each group, and the figure just below the mean is its standard error. The mean frequency of response once the criterial performance has been reached is presented for each group, and the figure just below the mean is its standard error. The data for animals 11 and 14 were not utilized in computing the mean scores for their groups. The capital letters 'LF' refer to 'left-forelimb,' and were placed at the head of each column to show that even though the locus of the shock was elsewhere, the bell evoked flexions of this member. The two columns under animal 11, headed 'LF' and 'LH,' refer respectively to left forelimb and left hindlimb flexions elicited by the CS. For further explanation see the text.

Group	I				II				III					IV				V			
Shock-locus	Right Forepaw				Right Hindpaw				Left Hindpaw					Right Thorax				Left Forepaw			
Animal	1	2	3	4	5	6	7	8	9	10	11		12	13	14	15	16	18	17	19	20
Test-period	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LF	LH	LF	LF	LF	LF	LF	LF	LF	LF	LF
1	75	75	80	85	65	75	75	85	85	85	75	0	95	40	5	40	25	90	90	95	85
2	85	95	90	85	80	95	95	90	100	100	90	0	100	75	0	65	80	90	95	100	90
3	95	100	80	95	95	85	100	100			80	0		95	5	85	85	95	100		100
4	100		100	100	90	95					80	0		90	0	100	95	95			
5					100	100					10	0		95	0		100	100			
6											5	50		95	0						
7											0	90		100	0						
8											15	60			0						
9											70	15			0						
10											45	45			0						
Mean	3.75 T-P				4.00 T-P				2.00 T-P					5.33 T-P				3.25 T-P			
σ_M	0.39 T-P				0.57 T-P				0.00 T-P					0.88 T-P				0.70 T-P			
1	95	95	90	90	90	90	95	95	90	100			95	100		95	95	95	100	95	100
2	100	95	95	100	100	100	90	95	100	95			95	95		100	100	90	90	95	100
3	100	90	75	100	95	95	95	100	100	95			100	100		85	95	100	100	95	95
4	100	100	95	90	95	100	95	90	100	100			100	100		95	100	90	100	100	100
5	95	95	90	95	95	100	95	95	100	100			100	100		95	90	85	95	95	95
Mean	94.25%				95.25%				98.00%					96.33%				95.75%			
σ_M	1.32%				0.77%				0.81%					1.39%				0.97%			

The four animals in Group I, which were shocked on the right forepaw, responded to the bell with conditioned flexions of the left forelimb. At no time did these animals respond with right forelimb flexion to the CS. Reconditioning of the left forelimb response proceeded rapidly, the group attaining the criterial performance of 100 percent CR in a mean of 3.75 T-P[3] (σ_M = 0.39 T-P). The control animals, Group V, where the locus of shock was unchanged, reached the criterial level in a mean of 3.25 T-P (σ_M = 0.70 T-P). The difference between these two means, 0.50 T-P ($\sigma_{diff.}$ = 0.80 T-P), when subjected to Fisher's test of the significance of differences between small samples (3), is found to be without significance.[4] Such a difference as this might be expected by chance 29 out of 100 times. Turning now to the effectiveness of right forepaw shock in maintaining conditioned left forelimb flexion once it has been re-established, one finds that the mean frequency of response for the 5 test-periods after the criterial performance to be 94.25 percent (σ_M = 1.32 percent) for Group I and 95.75 percent (σ_M = 0.97 percent) for Group V. The difference between these means, 1.50 percent ($\sigma_{diff.}$ = 1.64 percent), has a p value of 0.20. Therefore, once conditioned left forelimb flexion has been established and extinguished, change in the locus of shock from the left forepaw to the right forepaw results in no difference in the reconditioning and maintenance of conditioned left forelimb flexion.

Change in the locus of shock from the left forepaw to the right hindpaw produced similar results. Reconditioning of left forelimb flexion proceeded rapidly, with no right hindlimb flexions occurring to the CS at any time. The animals of Group II required a mean of 4.00 T-P (σ_M = 0.57 T-P) for reconditioning and gave a mean CR-frequency of 95.25 percent (σ_M = 0.77 percent). The differences between these means and those of the control group are 0.75 T-P ($\sigma_{diff.}$ 0.90 T-P) and 0.50 percent ($\sigma_{diff.}$ = 1.24 percent), the re-

[3] T-P—abbreviation for test-period.

[4] The ratio of any difference to its own standard error is called t. With the t value one can enter 'Student's' tables and find the p value. When p is 0.02 (which signifies that the difference in question might be expected twice in 100 samples drawn at random from a homogeneous population) or less, the difference is regarded as significant. When p is greater than 0.02, the difference is not significant.

spective p values being 0.23 and 0.35. Therefore, right hindpaw shock is as effective in the re-establishment and maintenance of left forelimb flexion as is left forepaw shock.

With the left hindpaw as the locus of shock, not all of the animals of Group III attained the criterial level of conditioned left forelimb flexion. The immediate effect of left hindpaw shock with animal number 11 was to recondition left forelimb flexion. The CR-frequency was 75 percent for the first test-period and 90 percent for the second, but thereafter it declined (Table I). On the sixth test-period, left hindlimb flexion became conditioned. By the tenth test-period, flexion of either or both the left forelimb and left hindlimb was evoked by the CS, but since there seemed little likelihood of reconditioning left forelimb flexion to the criterion, work with this animal was not continued. The other three animals of this group, however, reached the criterion rapidly, without once giving a CR of the left hindlimb. If the data of animal number 11 are omitted, these three animals reached the criterial performance in a mean of 2.00 T-P (σ_M = 0.00 T-P) and gave a mean CR-frequency of 98.00 percent (σ_M = 0.81 percent). Comparing these means with those of Group V, differences of 1.25 T-P ($\sigma_{diff.}$ = 0.70 T-P) and 2.25 percent ($\sigma_{diff.}$ = 1.26 percent) are obtained, with p values respectively of 0.07 and 0.06. For these three animals then, left hindpaw shock is as effective in re-establishing and maintaining left forelimb flexion to the bell as was left forepaw shock for the control animals. While animal number 11 did not reach the criterion set up for the re-establishment of conditioned left forelimb flexion, it did on the second test-period give a CR-frequency of 90 percent. The data of this animal do not then contradict seriously the generalization that shock applied to the left hindpaw is as effective in the re-establishing and maintaining of left forelimb flexion as is shock to the left forepaw. In all probability, some uncontrolled factor or factors in the experimental situation, of which the experimenter was unaware, are responsible for the behavior of animal number 11.

As with Group III, one animal in Group IV (number 14) failed to respond to the CS with left forelimb flexion. At the

end of the tenth test-period the picture was still the same; bell paired with shock to the right thorax had completely failed to re-establish conditioning of the left forelimb. Nor did this procedure produce a conditioning of trunk curvature or altered respiration, UR's produced by the thoracic shock. These responses were never evoked by the CS with the remaining three animals of this group. Instead, with shock applied to the right thorax, the criterial response of left forelimb flexion was attained in a mean of 5.33 T-P (σ_M = 0.88 T-P) and they gave a mean CR-frequency of 96.33 percent (σ_M = 1.39 percent). When these means are compared with those of Group V, differences of 2.18 T-P ($\sigma_{diff.}$ = 1.12 T-P) and 0.58 percent ($\sigma_{diff.}$ = 1.69 percent) are obtained, with respective p values of 0.06 and 0.38. For these three animals, shock applied to the right thorax is as efficient in the reconditioning and maintenance of left forelimb flexion as was left forepaw shock for the control animals. But with the absolute failure of shock at this locus to recondition left forelimb flexion in animal number 14, it is evident that shock to the right thorax is not as effective as shock to the left and right forepaws, and the left and right hindpaws in the reconditioning and maintaining of left forelimb flexion to bell.

With left forelimb flexion no longer instrumental in shock-avoidance, CR's of the limb where shock was applied soon developed (Table II). Left forelimb flexion was completely extinguished in five cases (animals number 1, number 3, number 4, number 9, and number 10) by the time conditioning of the other member had reached the 100 percent response-criterion. There was either no extinction or incomplete extinction of left forelimb flexion by the time conditioning of the other member had reached the 100 percent response-criterion in the remaining six animals, so they exhibited the phenomenon of 'ambiguous conditioning.' Three of the six animals in the experiment by Kellogg and Walker exhibited 'ambiguous conditioning.' So, it seems that approximately half of any random sample of dogs exhibit this phenomenon, when the shock is transferred from one limb to another, and CR's of the second limb are made contingent for shock-avoidance.

TABLE II

The first section of the table gives the results when flexions of the right forelimb (Group I), of the right hindlimb (Group II), and of the left hindlimb (Group III) were made instrumental in the avoidance of shock at those loci. The second section of the table gives the results of extinction, when shock was omitted altogether. And the third section of the table gives the reconditioning results when shock to the left forepaw was avoided either by flexions of the left forepaw or of the limb where shock had been applied previously. The capital letters 'LF' refer to the left forelimb, 'RF' to the right forelimb, 'RH' to the right hindlimb, and 'LH' to the left hindlimb. The figures in the columns represent the percent of flexion-response of the given member to the twenty presentations of the CS given each test-period.

Group	I								II								III					
Shock-locus	Right Forepaw								Right Hindpaw								Left Hindpaw					
Animal	1		2		3		4		5		6		7		8		9		10		12	
Test-period	LF	RF	LF	RF	LF	RF	LF	RF	LF	RH	LF	RH	LF	RH	LF	RH	LF	LH	LF	LH	LF	LH
1	100	0	100	0	30	20	95	0	100	0	90	55	100	25	100	10	100	0	100	0	100	0
2	100	0	100	0	5	60	45	10	100	0	100	60	100	40	100	0	100	0	45	25	60	40
3	100	0	85	0	0	80	60	35	85	20	80	75	50	75	100	30	100	0	15	70	40	70
4	50	45	50	15	0	95	45	50	55	45	85	85	40	45	85	75	100	0	0	100	65	85
5	75	20	60	15	0	90	10	90	15	65	90	60	75	80	75	60	100	0			30	45
6	0	65	50	25	0	90	10	80	5	80	90	85	80	80	90	65	90	0			35	60
7	40	35	25	50	5	90	5	85	20	65	90	75	85	90	90	90	45	25			15	100
8	5	60	5	80	0	90	0	90	15	90	90	85	100	80	90	80	0	90				
9	0	70	5	95	0	100	0	90	5	80	90	90	100	80	100	85	0	95				
10	0	80	0	85			0	95	5	80	100	80	85	100	90	95	0	100				
11	5	85	20	100			0	85	35	80	100	75			100	85						
12	0	90					0	100	5	95	100	90			90	90						
13	0	85							10	95	100	95			90	95						
14	0	90							15	90	100	95			100	100						
15	0	85							5	85	90	75										
16	0	90							10	90	100	100										
17	0	90							10	100												
18	0	90																				
19	0	85																				
20	0	90																				
21	0	100																				

TABLE II—*Continued*

Group	I								II								III					
Shock-locus	Right Forepaw								Right Hindpaw								Left Hindpaw					
Animal	1		2		3		4		5		6		7		8		9		10		12	
Test-period	LF	RF	LF	RF	LF	RF	LF	RF	LF	RH	LF	RH	LF	RH	LF	RH	LF	LH	LF	LH	LF	LH
1	0	25	10	65	0	45	0	25	15	50	100	90	55	15	90	45	0	30	10	70	25	85
2	0	0	10	40	0	15	0	0	5	20	95	100	45	0	95	30	0	0	15	15	55	35
3			0	5	0	10			0	0	100	55			50	15			10	15	55	10
4			0	20	0	0					60	45			55	0			5	20	45	0
5			0	0							75	90							15	30		
6											95	65							20	35		
7											65	65							5	45		
8											65	55							20	15		
9											80	45							10	35		
10											30	0							0	20		
11																			10	40		
12																			10	30		
13																			0	25		
14																			0	20		
15																			0	10		
16																			0	15		
17																			0	25		
18																			0	15		
19																			0	0		
1	90	0	45	45	0	55	35	30	60	20	90	10	65	0	90	0	5	15	0	95	95	0
2	75	0	55	30	0	60	80	0	95	15	100	20	100	0	100	5	90	0	0	100	95	0
3	100	0	100	0	20	75	75	15	100	0							95	0			100	0
4					55	30	90	0									100	0				
5					70	30	100	0														
6					65	30																
7					80	5																
8					85	5																
9					65	20																
10					80	10																
11					85	10																
12					100	0																

With Group I, the conditioning of right forelimb flexion required the same amount of time as the original conditioning of left forelimb flexion, the difference between the means being 1.50 T-P ($\sigma_{diff.}$ = 3.21 T-P), with a p value of 0.46. Similarly, with Group II, the conditioning of right hindlimb flexion required approximately the same number of test-periods as the original conditioning of left forelimb flexion; the difference between the means was 3.50 T-P ($\sigma_{diff.}$ = 1.79 T-P), with a p value of 0.05. With Group III, the difference between the mean time required for conditioning of the left hindlimb and the original conditioning of the left forelimb, 4.66 T-P ($\sigma_{diff.}$ = 1.93), is somewhat greater, but with a p value of 0.03 is not a significant difference. (See Tables II and III for further data on this question.) This result, of equality in time required in the transfer of conditioning and in time required for original conditioning, is contrary to that obtained by Kellogg and Walker (**8**). They found that more trials were required for the original conditioning of right forelimb flexion than in the transfer to conditioned left forelimb flexion.

These authors also found that the reconditioning of right forelimb flexion took fewer trials than either the original conditioning of right forelimb flexion or the transfer to left forelimb flexion. Similar results were obtained in the present experiment. Reconditioning of left forelimb flexion with shock at some other locus required significantly fewer trials than either the original or transfer conditioning with all groups. (Table III). The p values of all differences between the means for each group were less than 0.02.

The extinction of conditioned right forelimb flexion required significantly fewer trials than did the extinction of left forelimb flexion for the animals of Group I. The difference of 3.00 T-P ($\sigma_{diff.}$ = 1.06 T-P) has a p value of 0.01. On the other hand, with Groups II and III, the extinction of left forelimb flexion and of right and left hindlimb flexion required about the same number of trials. The differences between the means of Group II (0.50 T-P; $\sigma_{diff.}$ = 2.02 T-P) and of Group III (2.33 T-P; $\sigma_{diff.}$ = 5.58 T-P) have respective

TABLE III

The relative difficulty of original left forelimb conditioning (o), left forelimb reconditioning after extinction (R), conditioning of the response produced by shock at the new locus (T), and the reconditioning of left forelimb flexion with the return of shock to the left forepaw (2R) is given. The original extinction of the left forelimb flexion-response (E) and the extinction of responses established by shock at the new locus (2E) are also compared. All scores are in terms of the number of test-periods required to reach the specified criterial performance. The figure in parenthesis after each group mean is its standard error.

Group	I				II				III		
Shock-locus	RF				RH				LH		
Animal	1	2	3	4	5	6	7	8	9	10	12
o	17	14	18	10	10	11	9	13	10	13	12
Mean	14.75 (1.79)				10.75 (0.88)				11.66 (0.87)		
R	4	3	4	4	5	5	3	3	2	2	2
Mean	3.75 (0.39)				4.00 (0.57)				2.00 (0.00)		
T	21	11	9	12	17	16	10	14	10	4	7
Mean	13.25 (2.66)				14.25 (1.56)				7.00 (1.73)		
2R	2	2	12	5	3	2	2	2	4	2	3
Mean	5.25 (2.35)				2.25 (0.22)				3.00 (0.63)		
E	8	5	7	5	6	3	2	6	4	9	5
Mean	6.25 (0.75)				4.25 (1.02)				6.00 (1.53)		
2E	2	5	4	2	3	10	2	4	2	19	4
Mean	3.25 (0.75)				4.75 (1.74)				8.33 (1.73)		

p values of 0.41 and 0.35. (See Tables II and III for further data on this question.)

When after extinction of the transferred CR, the shock was returned to the left forepaw, and either left forelimb flexion or flexion of the limb which had just been extinguished were instrumental in avoiding shock, conditioned left forelimb flexion was dominant. In all but one case, left forelimb

flexion was rapidly reconditioned and reached the response-criterion within a few test-periods (see Tables II and III). Animal number 10 gave a 100 percent left hindlimb CR on the second test-period of bell with shock to the left forepaw, without giving any conditioned left forelimb flexions at all. The animals of Groups II and III were reconditioned in the same number of trials as in the first reconditioning, but with significantly fewer trials than in the original or transfer conditioning (see Table III). This same result is true of the animals of Group III, if we consider the reconditioning of left hindlimb flexion in animal number 10 when shock was applied to the left forepaw, to be functionally equivalent to the reconditioning of left forelimb flexion in the other two animals.

'Ambiguous conditioning' occurred in all but four of the animals during reconditioning with shock returned to the left forepaw. Of the ten animals in which left forelimb flexion was reconditioned to the criterial level, all but two made no CR's during the last test-period of other than the left forelimb (Table II). Once two flexion responses of different limbs have been conditioned to the same stimulus, the locus of shock serves as a stimulus for a dominant response to the CS of the limb to which it is applied.

The present writer agrees with the formulation of 'ambiguous conditioning' given by Kellogg and Walker.[5] 'Am-

[5] Kellogg and Walker (8) suggest that the motivating effect of the shock may be independent of its locus of application on the skin and that 'ambiguous conditioning' might be expected to continue as long as there was any shock at all—no matter where it was applied. They suggest that such an implication follows from the work of Finch and Culler (3) and Brogden and Culler (1), who maintained conditioned right forelimb flexion to higher order stimuli by means of shock applied to the left thorax as a constant incentive. Such an implication does *not* follow from the work of these investigators. In the first place, thoracic shock was never paired with stimuli which had been paired with shock to the right forepaw. In the second place, pairing of the second order stimulus with thoracic shock was not immediately successful in maintaining conditioned right forelimb flexion to the second order stimulus. There was no evidence whatever to indicate that the motivating effect of the shock is independent of the locus of application in reinforcing right forelimb flexion to the higher order stimuli. It was only with training and when right forelimb flexion was made instrumental in avoiding shock to the left thorax that the higher order responses were elaborated. As the present investigation has clearly shown, the motivating effect of shock is independent of its locus of application, only when some particular response (left forelimb flexion) is instrumental in the avoidance of shock at that locus (loci other than the left forepaw).

biguous conditioning' is a case of slow or delayed transfer, and prolonged shock-stimulation of one limb, *if flexion of this limb is instrumental in shock-avoidance*, would cause the response of the first conditioned limb to disappear.

Discussion

The experimental evidence clearly substantiates the hypothesis proposed in the introduction of this paper. If left forelimb flexion to shock is conditioned and then extinguished, the CS will evoke the extinguished CR when it is paired with shock at a new locus and when left forelimb flexion alone is instrumental in shock-avoidance. Also, once reconditioning has taken place through the application of shock at a new locus, conditioned left forelimb flexion is maintained by shock at its new locus as effectively as by left forepaw shock. Loci of shock which were effective are: right forepaw (Group I), right hindpaw (Group II), and left hindpaw (Group III). While left hindpaw shock did not produce re-conditioning of the left forelimb to the criterial level in all the animals of Group III, the one failure, animal number 11, did attain a 90 percent response on the second test-period, before left hindlimb flexion to bell made its appearance. Shock to the right thorax was not as effective as were other loci of shock. One animal in Group IV failed completely to give conditioned left forelimb flexion-responses. For the others, however, shock applied to the right thorax, was as effective in the reconditioning and maintenance of left forelimb flexion as was left forepaw shock for the control animals.

Since conditioned left forelimb flexion, when it has been extinguished, can be reconditioned and maintained as effectively by shock applied at loci other than the left forepaw, it follows that during the original conditioning, some process akin to generalization must have taken place. If a given response of an organism is conditioned to a particular stimulus, it has been shown that other stimuli will also evoke the response, even though these stimuli have never been used in the experimental procedure. This generalization is usually confined, or at least is more pronounced, within the sense modality

of the CS. Hilgard and Marquis (**6**) have applied the term sensory generalization to this process to differentiate it from response generalization, where a stimulus which through training has come to elicit a particular response, may under some circumstances, evoke a different response without particular training. Sensory generalization is a generalization of stimuli which evoke a definite pattern of response. Since eliciting a response of a certain character is one of the functions of the US, which through conditioning is taken over by the CS, why should there not be a generalization of the other function of the US, that of providing the incentive for response? With conditioned flexion, shocks of varying intensity (and quality?) are effective in maintaining conditioning. With conditioned salivation, different amounts and different kinds of food are likewise effective in maintaining conditioning. This is certainly evidence of generalization, a sensory generalization. With change in the locus of shock, when left forelimb flexion is re-established and maintained as effectively as when the shock-locus is unchanged, we have still further evidence of generalization. Sensory generalization shows a gradient; the less the similarity of the stimulus to the CS, the less the magnitude or frequency of the response which it evokes. No such generalization gradient occurred with different loci of shock in reinforcing conditioned left forelimb flexion.[6] While the generalization of reinforcement with change in shock locus is certainly a sensory generalization, it differs in two important respects from the phenomenon which is usually designated by this term. First, the functions of the stimuli are different. With sensory generalization, the generalization is one of stimuli which evoke a definite response-pattern. With change in shock-locus, the generalization is one of reinforcement, of maintaining a definite response-pattern. Secondly, with sensory generalization, there is a gradient of response magnitude or frequency. With change in shock-locus, there is no re-

[6] While shock applied to the left hindpaw and the right thorax might be considered less efficient than shock applied to the left and right forepaws and the right hindpaw, since one animal each from Groups III and IV failed in the reconditioning of left forelimb flexion, there is no evidence of a gradient in terms of spatial orientation with respect to the left forepaw as the point of origin.

sponse-gradient. Therefore, instead of treating the functional equivalence of shock at loci other than the left forepaw in reconditioning and maintaining left forelimb flexion as a sensory generalization, let us designate it an *incentive generalization.*

Incentive generalization is equally as important as either sensory or response generalization. It is difficult to demonstrate this for animal behavior, as the number of stimuli which function as incentives is much more limited than those stimuli which function as signals. This is particularly true of the laboratory environment. It is not so true of human behavior, where the large number of stimuli which function as incentives do not make the disparity between stimuli, which function as signals and as incentives, obvious, if such a disparity exists here.

One particular CR of a human organism may have been originally reinforced by punishment applied directly to the responding member. But once the CR has been firmly established, or even before, punishment may be applied at many areas of the organism and by many different instruments without diminishing the strength of the CR. Further incentive generalization will in all likelihood take place, so that the verbal threat of punishment, or some expression of social disapproval, either of which may take many forms, will effectively maintain the CR. A CR whose original reinforcement was some specific form of reward, will also show incentive generalization. If the reward was at first some specific food, other preferred foods will also function as incentives. Money, permission to go to the movies, different forms of social approval may all function, without specific training, as incentives in maintaining some specific CR of a child.

While direct experimental evidence is lacking of incentive generalization in the CR's of human beings, empirical observations make it seem likely that incentive generalization is a more important and widespread process with humans than with animals.

Summary of Conclusions

1. When left forelimb flexion to shock has been conditioned to the ringing of a bell and then extinguished, shock applied to other loci (right forepaw; right hindpaw; left hindpaw; and right thorax) is as effective in the reconditioning of left forelimb flexion to bell as is left forepaw shock, if left forelimb flexion alone is instrumental in shock-avoidance.

2. Once left forelimb flexion has been reconditioned to the criterial level with shock at other loci, conditioned left forelimb responses are as effectively maintained with shock at these loci as with shock applied to the left forepaw, when left forelimb flexion alone is instrumental in shock-avoidance.

3. The reconditioning and maintenance of left forelimb flexion with shock at other loci is indicative of a generalization of the incentive-function of the US. This phenomenon is designated, therefore, as incentive generalization, to differentiate it from sensory generalization and response generalization.

4. An equal number of test-periods was required in the original conditioning of left forelimb flexion and in the conditioning of the flexion-response evoked by shock at its new loci, when flexions of these members were made the instruments of shock-avoidance (Group I—right forelimb flexion; Group II—right hindlimb flexion; Group III—left hindlimb flexion).

5. With six of the eleven animals, there was either no extinction or incomplete extinction of left forelimb flexion by the time conditioning of the other member had reached the 100 percent response-criterion, so they exhibited the phenomenon of 'ambiguous conditioning.'

6. Reconditioning of left forelimb flexion with shock at some other locus required significantly fewer trials than either the original or transfer conditioning.

7. The extinction of the transfer conditioning required either significantly fewer or an equal number of trials to the extinction of left forelimb flexion.

8. When after extinction of the transferred CR, the shock was returned to the left forepaw, and either left forelimb flexion or flexion of the limb where shock had been applied, were instrumental in shock-avoidance, conditioned left fore-

limb flexion was dominant. Reconditioning under these conditions required the same number of trials as the original reconditioning of left forelimb flexion, and significantly fewer trials than original left forelimb conditioning and transfer conditioning.

9. 'Ambiguous conditioning' occurred in all but four of the eleven animals during reconditioning with shock returned to the left forepaw. The phenomenon of 'ambiguous conditioning' is considered to be a case of slow or delayed transfer, where prolonged shock-stimulation of one limb, *if flexion of this limb is instrumental in shock-avoidance*, would cause the response of the limb first conditioned, to disappear.

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THE MEASUREMENT OF MASKED AUDITORY THRESHOLDS

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A program of research has been undertaken for the explicit purpose of investigating timbre as it relates to harmonic structure, frequency level, and intensity level. This first report of the work deals mainly with the measurement of masked thresholds, although it includes, of necessity, a description of apparatus and a brief discussion of problems of measurement.[1]

Data are to be presented on what can appropriately be called *masked absolute thresholds* and *masked differential*

[1] It should be stated, at the outset, that a satisfactory definition of timbre has not been formulated. In fact, with knowledge of timbre as fragmentary as it is, a definition other than a negative one must be largely conjectural. To say, as is so often done, that timbre is conditioned by harmonic structure, frequency level, and absolute intensity is not to define timbre psychologically. Perhaps the most meaningful definition that can be offered, for the present, is as follows: Timbre is that attribute of auditory experience by means of which tones, alike in pitch, loudness, and duration, and yet dissimilar, are differentiated. But a pertinent question remains unanswered: Differentiated in what respects? All that the definition states is that there are differences in timbre and that timbre *is not* pitch, loudness, nor duration. It does not state the dimensional or classificatory bases of discrimination.

The basic difficulty seems to arise from the fact that timbre, unlike either pitch or loudness, is multi-dimensional. (In its dimensional characteristics, timbre is somewhat analagous to hue in vision.) Naive descriptions of various complex tones typically include such words as rich, hollow, harsh, thin, dull, shrill, bright, etc., etc., but the descriptions are seldom consistent from one observer to another; and even when observers who are musically as well as psychologically sophisticated are asked to describe various complex tones, they usually fail to show satisfactory agreement in their use of 'colorful' terminology.

Despite confusion of this type, it is known that modifications in the harmonic structure of complex tones give rise to experiential changes which are different from changes in either pitch or loudness. These changes are to be regarded as changes in timbre; and even though timbre cannot as yet be given a satisfactory definition, measurements can be made of the amount of change in harmonic structure which is necessary to induce perceptible differences among complex tones. Measurements of this kind are reported here. The results of the measurements should have an important bearing on problems relating not only to the definition but also to the systematic analysis of timbre.

thresholds. The meaning of these two terms can probably best be indicated by the use of a specific illustration. Fig. 1 is a graphic representation of one of the complex tones which have been investigated. In the figure, intensity level (db.

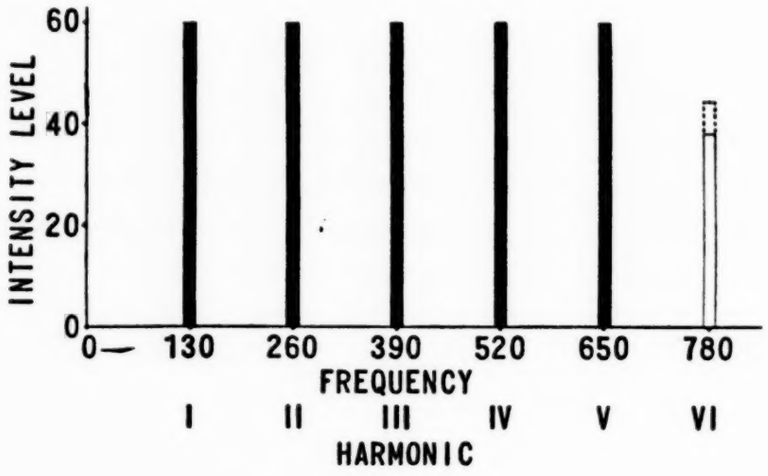

FIG. 1

above 10^{-16} watt) is plotted against frequency. Harmonic number is also shown on the abscissa. As indicated, the fundamental frequency was 130 cycles. Harmonics I to V, inclusive, were each set at an intensity level of 60 db. These were the *masking harmonics*. The first experimental problem, for the specific series here illustrated, was to measure the intensity level at which harmonic VI could barely be detected in the presence of the five masking harmonics. This intensity level would be the masked absolute threshold of harmonic VI. More generally, when a single harmonic is adjusted in intensity level until it is barely perceptible in the presence of one or more masking harmonics of specified frequency, intensity, and phase, its intensity level at that point is called its masked absolute threshold for the conditions specified. In Fig. 1, the top of the full-line portion of the open vertical bar represents the masked absolute threshold of harmonic VI when measured in the presence of the first five harmonics, each at an intensity level of 60 db and all with the same phase angle. Harmonic VI was the *masked harmonic*.

The broken-line portion of the open vertical bar in Fig. 1 represents a masked differential threshold of harmonic VI.

In this case, the *first* differential step is depicted. In general, a masked differential threshold of a given masked harmonic is the amount (in db) that the harmonic must be raised, after it is already at or somewhere above its masked absolute threshold, to give rise to a just perceptible change. The number, intensity levels, and phase angles of the masking harmonics, as well as the level of the masked harmonic at which measurement is made, must always be indicated. For specified intensity levels and phase angles of a specified group of masking harmonics, there can be only one masked absolute threshold of a given masked harmonic, but there can be many different masked differential thresholds.

It is obvious, for example, that masked differential thresholds of harmonic VI could be measured for various levels above its masked absolute threshold. It is also obvious that both masked absolute and masked differential thresholds could be measured for any other harmonic in the group. For example, thresholds for harmonic I could be determined when harmonics II to VI, inclusive, were the masking harmonics; or thresholds for harmonic III could be measured when harmonics I, II, IV, V and VI were the masking harmonics. It would not be necessary to use five masking harmonics because any other number could be chosen within the limits placed by the available apparatus. Nor would it be necessary to set the masking harmonics at 60 db and have them the same in intensity level. Furthermore, the phase angles of the masking harmonics could be adjusted in many different ways. In masking experiments with complex tonal stimuli, all decisions on the number, intensity levels, and phase angles of the masking harmonics which are used must be quite arbitrary. It might even be desirable to control the sensation level or the loudness level of the masking harmonics instead of their intensity level. For purposes of the investigation reported in this paper, it was arbitrarily decided to use five masking harmonics, all of which were the same in both intensity level and phase angle. The fundamental frequency was arbitrarily set at 130 cycles.

In the determination of threshold values, a modification

of the method of constant stimuli was employed. Any given stimulus tone had a duration of about 3.0 secs., and consisted of two parts: a *standard portion* and a *variable portion*, each about 1.5 secs. in duration. *Judgments were made in relation to the two portions of each stimulus tone.* When masked absolute thresholds were being measured, the standard portion of the stimulus tone consisted of five masking harmonics, while the variable portion consisted of the same masking harmonics *plus* some amount of the harmonic whose threshold was being determined. For example, for the case illustrated in Fig. 1, the standard portion consisted of harmonics I to V, inclusive, all at an intensity level of 60 db and all in phase. The variable portion consisted of these same five harmonics plus a desired amount of harmonic VI. When masked differential thresholds were being determined, the standard portion consisted of the masking harmonics and a desired above-threshold amount of the harmonic being explored, while the variable portion was the same except that the harmonic being explored was at a different level. It will be convenient, in the following exposition, to refer to the particular harmonic whose thresholds were being measured as the *masked harmonic.*

The generator used in the investigation was constructed so as to permit as many as five different intensity levels of the masked harmonic to be set in advance for an observational series; and 100 stimulus tones, in which the variable portion occurred at random (that is, sometimes before and sometimes after the standard portion), could be presented more or less automatically for a single run. Fig. 2 is a schematic repre-

FIG. 2

sentation of the stimulus situation. Two consecutive stimulus tones are shown, with a period of silence between them. In the tone represented at the left, the variable portion follows the standard portion; in the tone at the right, the sequence is reversed. Each stimulus tone began and ended

gradually but quickly so as to avoid audible transient effects, and the transition from the standard portion to the variable portion, or vice versa, also occurred without perceptible clicks.

The actual sound source was a calibrated 555 Western Electric receiver. An observer listened monaurally and made a judgment on each stimulus tone. He judged whether the masked harmonic was present in the first or the second half of the stimulus tone (or, during the measurement of masked differential thresholds, whether the masked harmonic was louder in the first or second half of the tone). It was usually necessary to provide for a short training period during which the observer listened to differences which were well above threshold and became familiar with the particular type of change which characteristically occurred when a particular harmonic was being explored.

Apparatus

The stimulus tones for the investigation were produced with a generator of the electrostatic type, the basic features of which have been described elsewhere (1). Inasmuch as a few important changes have been made since the original description was published, a short discussion of theory and of circuit arrangements will be given here.

With the generator, it is possible to produce sounds constituted of any or of all of 16 natural harmonics, the frequencies, intensities and phase angles of which are subject to control. Two schematic drawings are shown in Fig. 3. The 16 harmonics are generated independently by means of 16 variable condensers, the capacitances of which are varied systematically. When a rotor, connected as shown in the circuit at the bottom of Fig. 3, moves adjacent to a stator, a periodic change in capacitance is produced. This change in capacitance causes an alternating current to flow through the circuit. The frequency of the alternations depends upon the rotational speed of the rotor and the number of segments on the rotor. When the resistance R is low as compared with the impedance of the variable capacitance, the current i is equal to the potential E multiplied by the time-rate-of-change of the variable capacitance; that is,

$$i = E\, dc/dt.$$

The potential changes across the input resistance may be amplified. It is important to note that the grid potential, and hence the amplifier output, is directly proportional to E.

By means of properly designed rotor and stator units and by means of shielding methods which effect a definite and rather sharply defined flux pattern between the rotor and stator and which, at the same time, nullify external disturbances, a reasonably pure sinusoidal current is generated with each of the 16 variable condensors. All of the 16 harmonics have been analyzed individually with an electrical analyzer. These analyses reveal that in harmonics I to VI, inclusive, there are no stray components

above — 40 db, with one exception. The exception is in harmonic I where there is a stray 3rd whose level is — 32 db.[2] In harmonics VII to XVI, inclusive, for which multiple stator segments are used, there are no stray components above — 54 db. The subharmonics and spurious frequencies which may be caused by mechanical and acoustical vibrations are all below — 54 db. The noise level of the amplifying system is about 70 db below the usual operating level.

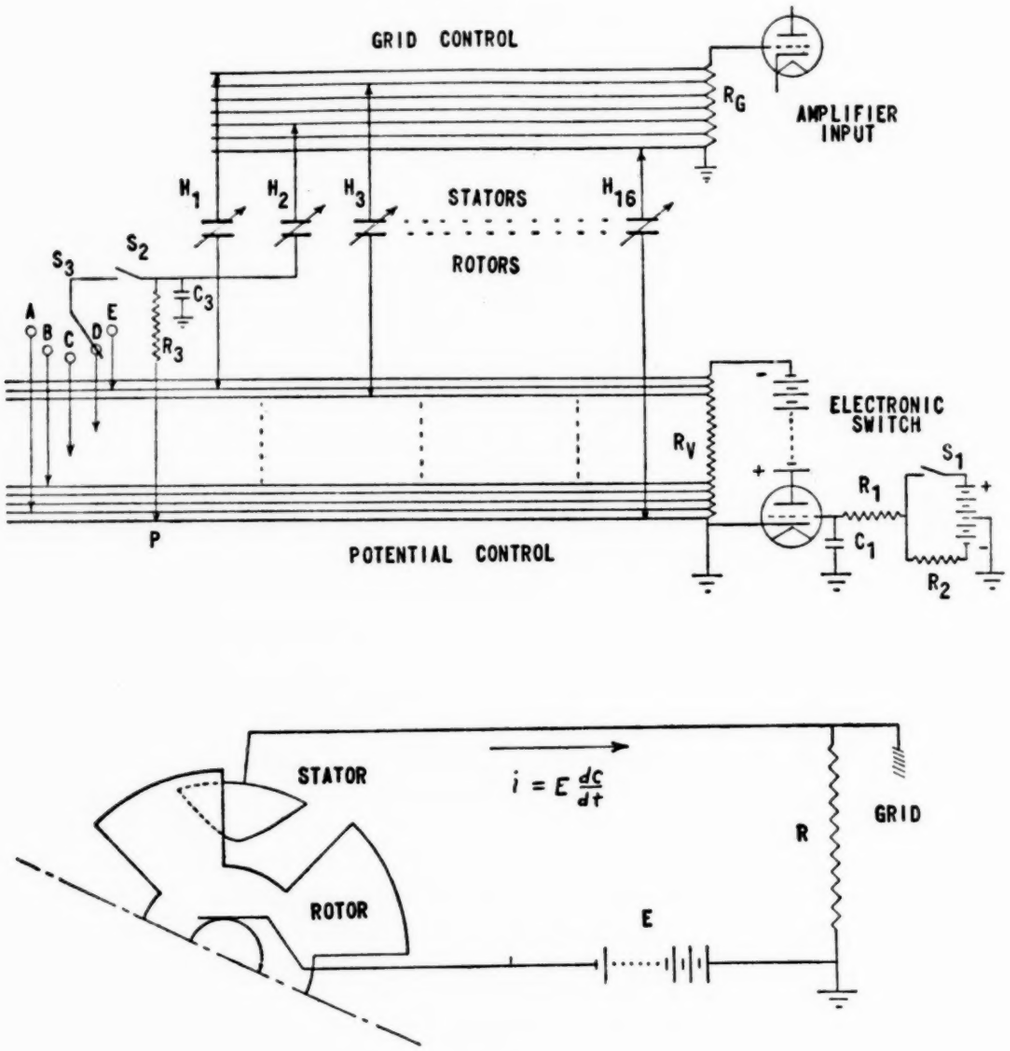

FIG. 3

All of the rotors are mounted on the same shaft. The number of segments on each rotor is so adjusted as to give a natural harmonic series. The fundamental frequency, which automatically conditions the frequencies of all other harmonics, depends upon the rotational speed and the number of segments on rotor 1. The relative phase angles of the harmonics may be adjusted by changing the alignments of the stator units.

[2] Series-resonant circuits have recently been inserted on the stator side of each of the first six generating units, with the result that at present there are no stray components above about —50 db in any of the 16 harmonics.

A schematic diagram of the generator with its control circuits is shown at the top of Fig. 3. The single generating units ($H_1, H_2, H_3 \ldots H_{16}$) are represented as variable condensers. Two methods, both separate from amplifier gain, are used to control the intensity of the individual harmonics. One method is to vary the input resistance of a harmonic through the shielded potentiometer R_G, which has a number of fixed taps and which is calibrated in fairly large decibel steps. This method is a 'grid control' of intensity. The other method of controlling intensity is to vary the potential on the rotor plates. This method gives the 'potential control' of intensity. The potential board permits variations through 50 steps of two percent each. The effective range in intensity for the method of grid control is 46 db, and for the potential control, 34 db. The total range of control for any selected amplification level is, therefore, 80 db. for each harmonic.

The output of the amplifier is led into a calibrated 555 receiver. The current through the receiver which is needed to produce desired intensity levels of individual harmonics is measured with a vacuum-tube voltmeter placed across a ten-ohm resistance connected in series with the voice coil of the receiver.

An electronic switch, which controls the potential supplied to the rotors, is used to avoid undesirable transient effects when the stimulus tone is turned on and off. The tone is caused to begin and end gradually but quickly. A diagram of the switch is shown in Fig. 3. In the construction of the switch, use was made of changes which arise in direct-current resistance between the cathode and plate of a triode when grid bias is varied. When S_1 is open, the tube is biased below its cut-off point; which means that there is no electron flow from cathode to plate and, consequently, no potential difference across R_V. On the other hand, when S_1 is closed, the grid is positive with respect to the cathode, and the resistance between cathode and plate becomes quite small as compared with the resistance of R_V, which is 50,000 ohms. Under these circumstances, the potential across R_V is essentially that of the battery supply. The rate of change in grid bias, and thus the time constant of the electronic switch, may be regulated by variations in R_1, R_2 and C_1. As used, the switch has a time constant of 0.15 sec. This time constant is sufficiently short so that the observer does not hear the stimulus tone as beginning and ending gradually, and yet it is sufficiently long to eliminate all perceptible transient effects. The electronic switch is turned on and off by means of a perforated moving tape, through the auxiliary switch S_1.

The perforated moving tape also operates switches S_2 and S_3. Switch S_1 is the master switch. It determines when the stimulus tone begins and when it ends. Switch S_3 is used to select, for a given stimulus tone, one of five pre-set potentials (A, B, C, D and E) which is applied to the rotor plate of the masked harmonic. For illustrative purposes, H_2 is shown in the diagram as the masked harmonic. Switch S_2 determines whether the potential is applied to the rotor of the masked harmonic during the first or the second half of the stimulus tone. When S_2 is open, the rotor of the masked harmonic assumes potential P, which may be at ground (as it is during determinations of masked absolute thresholds) or at some fixed value (as it is when masked differential thresholds are being explored). S_2 is either opened or closed at the middle of each stimulus tone. Possible 'clicks' arising from the action of S_2 are made inaudible by the use of R_3 and C_3.

Experimental Results

Masked Absolute Thresholds

The first part of the investigation was concerned with the measurement of masked absolute thresholds (m.a.t.'s). The m.a.t. of each of the six harmonics[3] was measured when it was sounded in the presence of the other five. Thus, six separate determinations of m.a.t. were called for.

Two observers were used, each of whom, while listening monaurally, judged whether the particular masked harmonic under investigation was present in the first or second half of the stimulus tone. The results for the two observers were never combined. To provide for fairly stable psychometric functions, the observers each made at least 400 (and usually as many as 600) judgments on each masked harmonic; that is, they each made from 80 to 120 judgments on each masked harmonic when it was set at each of five different intensity levels.

The m.a.t.'s were computed by linear interpolation. They were calculated as the intensity levels corresponding to the points where the various psychometric functions crossed the 75 percent line. Two typical functions (one for each observer) are shown in Fig. 4, where correct responses in percent are plotted against intensity level. The data were secured on harmonic VI. The experimental values are represented by dots, each value being based upon 120 judgments. The two vertical arrows indicate the intensity levels which correspond to the points where the functions cross the 75 percent line, the latter being designated by the horizontal arrow. The indicated intensity levels (33.5 and 38.0 db. for observers A and B, respectively) are, by definition, masked absolute thresholds.

The results of the threshold determinations are presented in Fig. 5. There is a separate graph for each of the two observers. Values of m.a.t. are represented by the tops of the solid portions of the vertical bars. For example, observer

[3] Harmonics I to VI, inclusive. As indicated already, the fundamental frequency was 130 cycles, all of the harmonics were in phase, and the five masking harmonics, in each instance, had intensity levels of 60 db.

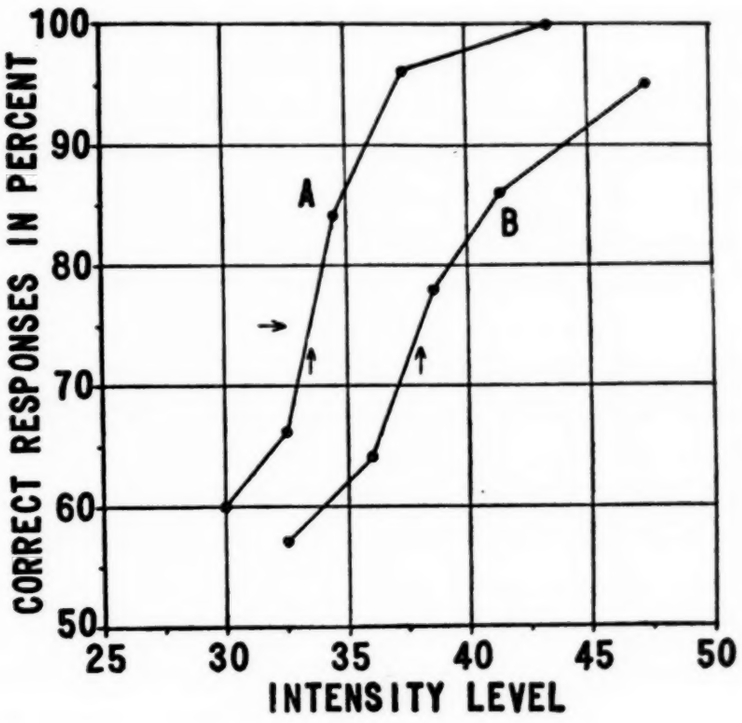
CORRECT RESPONSES IN PERCENT
100
90
80
70
60
50
A
B
25
30
35
40
45
50
INTENSITY LEVEL

FIG. 4

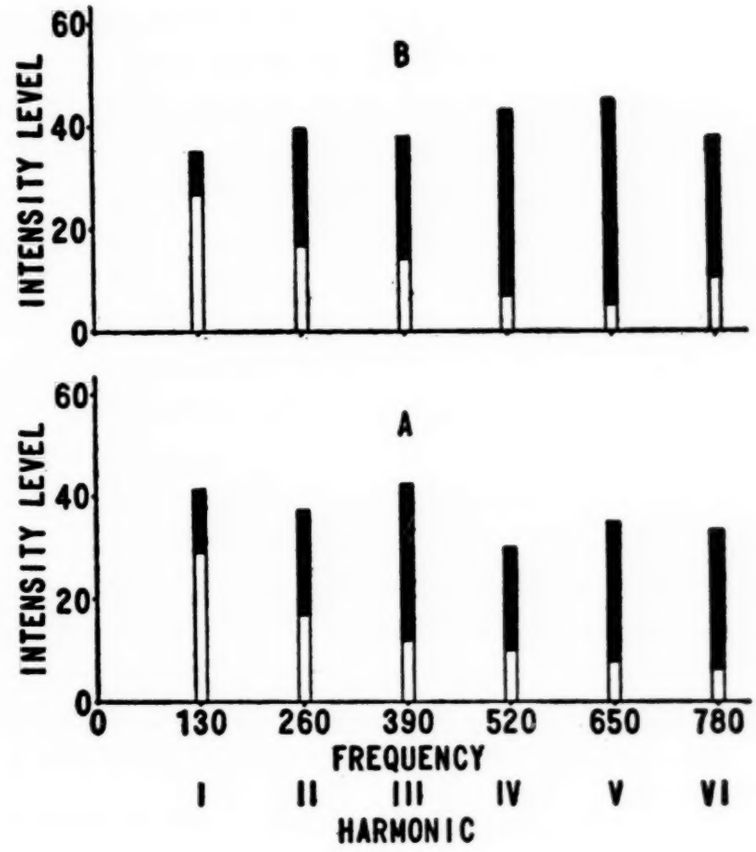
INTENSITY LEVEL
60
40
20
0
B
INTENSITY LEVEL
60
40
20
0
A
0
130
260
390
520
650
780
FREQUENCY
I
II
III
IV
V
VI
HARMONIC

FIG. 5

B's threshold for harmonic VI was about 38 db.[4] (See the upper graph.) His threshold for harmonic III was near the same level; for harmonic I, slightly below it; and for the other three harmonics, somewhat above. On the whole, the thresholds for observer A were lower than those for B.

The open portions of the various vertical bars in Fig. 5 are used to depict thresholds of audibility. The threshold of each harmonic was measured when it was presented alone, in the absence of effective masking. This threshold is the threshold of audibility, by common definition. The values are given by the tops of the open portions of the bars. The vertical extents of the solid portions of the bars are, therefore, representative of the sensation levels of the various harmonics when they were at their m.a.t.'s.[5]

The method employed in the measurement of thresholds of audibility should be indicated. Harmonic XVI, whose frequency was 2080 cycles, was used to delimit typical stimulus-tone periods. (See Fig. 2.) It sounded throughout successive stimulus periods, at a sensation level of about 10 db. It was faint but still sufficiently steady to define each period clearly. Its frequency was believed to be high enough to prevent any masking of the other harmonics. The particular harmonic whose threshold of audibility was being measured was presented randomly at desired levels, during either the first or the second half of the stimulus periods; and the observer judged its position. In this way, thresholds of audibility were determined quite exactly, and the method of measurement was directly comparable to the method of measuring m.a.t.'s.

The results presented in Fig. 5 are not easy to interpret. The change in the threshold of audibility with frequency was in keeping with the findings of other investigators, but the differences in masked absolute threshold were rather puzzling. There were reasons (the general nature of masking, etc.) for

[4] This means that, for observer B, harmonic VI required an intensity level of about 38 db. to be barely detectable in the presence of masking harmonics I to V, inclusive, with each set at 60 db.

[5] The sensation level of any sound is the amount (in db) by which its intensity exceeds its intensity at the threshold of audibility.

expecting the m.a.t.'s of the harmonics in the middle of the series (III and IV, say) to be greater than those of harmonics I and VI. The results for observer B were more or less in line with this expectation, but those for A were not. The explanation for the fact that A's threshold for IV was the lowest of all, or for the fact that his threshold for VI was lower than that for V, could not be given in terms of simple masking theory.

It was thought possible that the magnitudes of the m.a.t.'s were conditioned, at least in part, by the specific action of subjective (or aural) harmonics. If, as is generally believed, subjective harmonics are due to actual vibrations in the cochlea, then such vibrations must have frequency, magnitude, and phase. Thus, it may be supposed that when a certain harmonic was introduced into a group of masking harmonics, interference between this harmonic and a corresponding subjective component occurred. It follows that the interference was either constructive or destructive in type, depending upon the phase relationship between the two interfering components. Suppose, for example, that masking harmonics I to V, inclusive, gave rise to a subjective harmonic VI having a certain magnitude and phase. When harmonic VI was introduced for purposes of measuring its m.a.t., there was bound to be interference between objective VI and subjective VI. The amount and kind of interference, and consequently the magnitude of the m.a.t. of harmonic VI, were, of necessity, some function of the phase relationship between the two VI's, the one objectively introduced and the other subjectively generated.

As a means of evaluating the foregoing conjectures, it was decided to measure the m.a.t. of a selected harmonic as a function of its phase angle. The stimulus conditions were different from those described above. The nature of the standard portion of the stimulus tone is indicated by the solid vertical bars in Fig. 6. Harmonics II to VI, inclusive, were the masking harmonics. They were in phase and each was set at an intensity level of 60 db. The problem was to measure the m.a.t. of harmonic VII as a function of its phase angle.

The purpose in using this altered stimulus condition was to find a combination of masking harmonics which was free from crucial stray components. In the altered stimulus, with har-

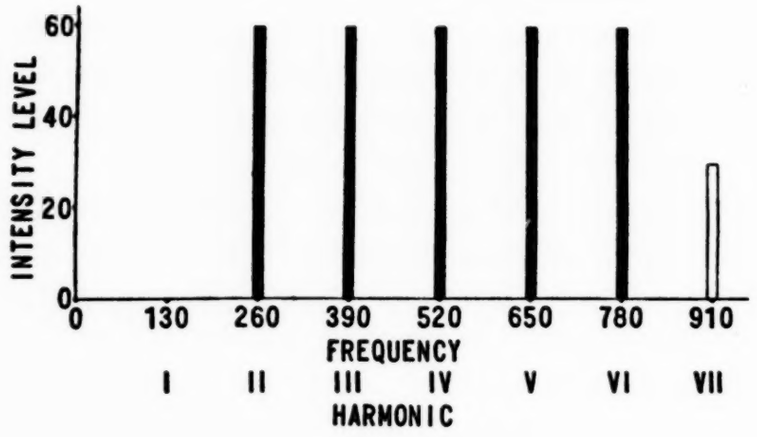

FIG. 6

monic I eliminated, there was not detectable amount of a stray VII. Consequently, the m.a.t. of VII could be measured without the possibility of encountering spurious interference effects, that is, interference effects due to a *stray* VII in the stimulus.

The results of the measurements are given in Fig. 7. Masked absolute threshold (of harmonic VII) is plotted against phase angle (of VII) in degrees. Seven separate threshold determinations were made for each of the two observers. From 400 to 500 judgments entered into the computation of each threshold.

The measured values are represented in the graph by dots, the dots having been connected with straight lines. It will be seen that, for either observer, there was a difference between the extreme values of m.a.t. of as much as 12 or 13 db. For example, the m.a.t. for observer A at a phase angle of 0° was 25 db., and at a phase angle of 180°, almost 38 db. A similar difference was found for observer B, although all of his thresholds were somewhat higher than those for observer A.

Obviously, if there had been a stray VII of fixed phase in the stimulus tone, the m.a.t. of harmonic VII would have varied as a function of its phase angle in some such manner as it did, with the amount of variation depending upon the mag-

nitude of the stray component. Because there was no detectable stray VII in the stimulus, the variations as found must be attributed to the interfering action of a subjective VII.[6]

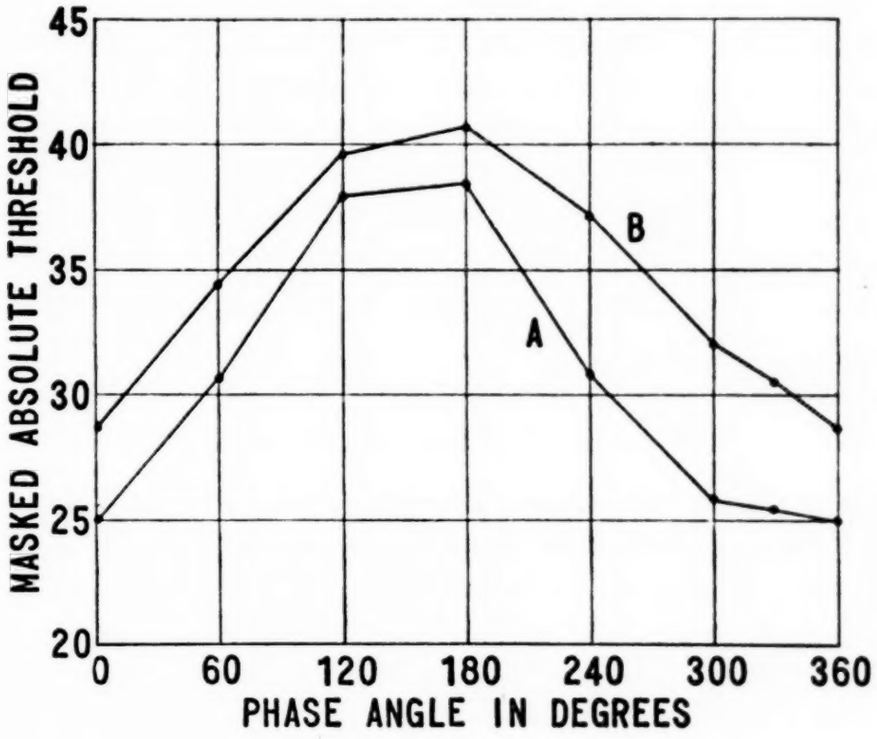

FIG. 7

It has been shown indirectly, then, that the m.a.t.'s presented in Fig. 7 were undoubtedly conditioned in part by the specific action of subjective tones. Unfortunately, there was no way of determining to what extent they were influenced by subjective tones, to what extent by stray components in

[6] That changes in m.a.t. with phase angle are due basically to interference between objective and subjective harmonics of the same frequency has been shown quite convincingly in two recent papers, one by Lewis and Larsen (3), the other by Lewis (2). Stimulus conditions were not the same as those described above, but they were comparable. Both of the papers contain, in addition to confirming evidence on interference, a full description of a method which may be used in determining the magnitudes of subjective tones from phase-angle data on m.a.t.'s. The method need not be explained here. However, its application to the data presented in Fig. 7 reveals that subjective harmonic VII had an intensity level of about 30 db for observer A and about 32 db for observer B. A more exact way of putting it would be to say that the magnitudes of subjective VII were essentially equivalent to magnitudes which would have been induced in the ears of the two observers if objective VII had been presented alone (that is, in the absence of masking) at the two designated intensity levels.

the stimulus, and to what extent by 'simple masking factors' (that is, by 'spread-out patches of disturbance' along the basilar membrane). There were stray components in the stimulus which, in intensity level, averaged around 14 db; and these surely played some part, although a relatively unimportant one. About all that can be said, by way of summary, is that the m.a.t.'s were complexly conditioned, especially by simple masking factors but also by specific interference phenomena. Future investigations of the same general problem should provide, first, for the elimination of stray components and, second (and more importantly), for a detailed study of the effects of interference between subjective and objective harmonics.

Masked Differential Thresholds

After masked absolute thresholds had been determined for each of the six harmonics (see Fig. 5), it was possible to make a systematic survey of masked differential thresholds (m.d.t.'s). The typical procedure was to determine, for each harmonic, the first differential step above its m.a.t., and then to make other measurements at representative higher levels. In the case of two or three of the harmonics, m.d.t.'s were determined step by step. For example, after the m.a.t. of harmonic VI had been measured, VI was included in the standard portion of the stimulus tone at its threshold level. Then, in the variable portion of the stimulus tone, VI was presented randomly at one of five different intensity levels, all of which were above its level in the standard. Observations on this series of tones yielded data with which the m.d.t. of VI could be computed. This value of m.d.t., when added to the m.a.t., gave an intensity level which was one differential step above the m.a.t. The second differential step was then measured in a comparable manner. In all, five masked differential thresholds were obtained on harmonic VI for each of the two observers. Representative m.d.t.'s were secured for each of the other five harmonics. Always, in the measurement of m.d.t.'s, the particular harmonic under investigation appeared in the standard portion of the stimulus tone at some specified level—

either at the level of its m.a.t. or at some higher level. In the variable portion of the stimulus tone, it appeared at one of five selected levels above its level in the standard portion.

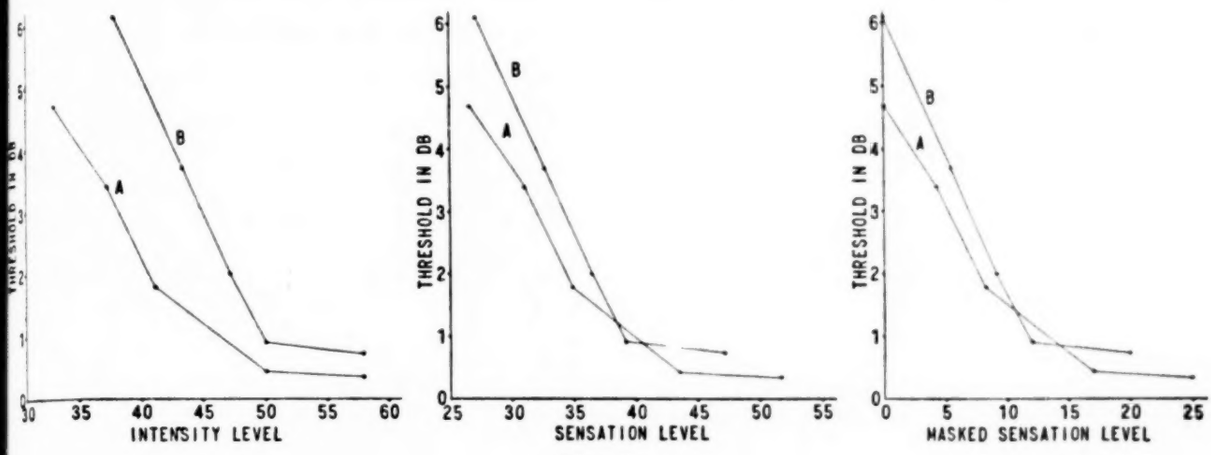

FIG. 8

The results for harmonic VI are presented in Fig. 8, where they are plotted in three different ways. In the left-hand graph, masked differential threshold in db is plotted against intensity level (db above 10^{-16} watt). There is a curve for each of the two observers. The measured values are represented by dots, and these have been connected with straight lines. For each observer, the value of the first differential step is plotted at the level of the m.a.t. Because the m.a.t.'s for the two observers were not the same, the first plotted points are displaced with respect to each other along the abscissa. It will be seen that the magnitude of m.d.t. decreased markedly with increases in the intensity level at which the threshold was measured. For example, the first differential step for observer B was slightly over 6 db, while his threshhold, at the highest intensity level used, was less than 1 db.

The same results are plotted in a different way in the middle graph of Fig. 8. In this case, threshold in db is plotted against sensation level. (See footnote 5.) In the right-hand graph, the ordinate still represents threshold in db, but the abscissa represents masked sensation level.[7] The three different ways of plotting the results were used as a

[7] The term 'masked sensation level' is here used to refer to the difference in db between intensity level and masked absolute threshold.

means of trying to decide whether the various m.d.t.'s, when considered together, were more uniquely related to intensity level, to sensation level, or to masked sensation level.

On the basis of the three sets of curves in Fig. 8, it might be concluded that there is little to choose between the rela-

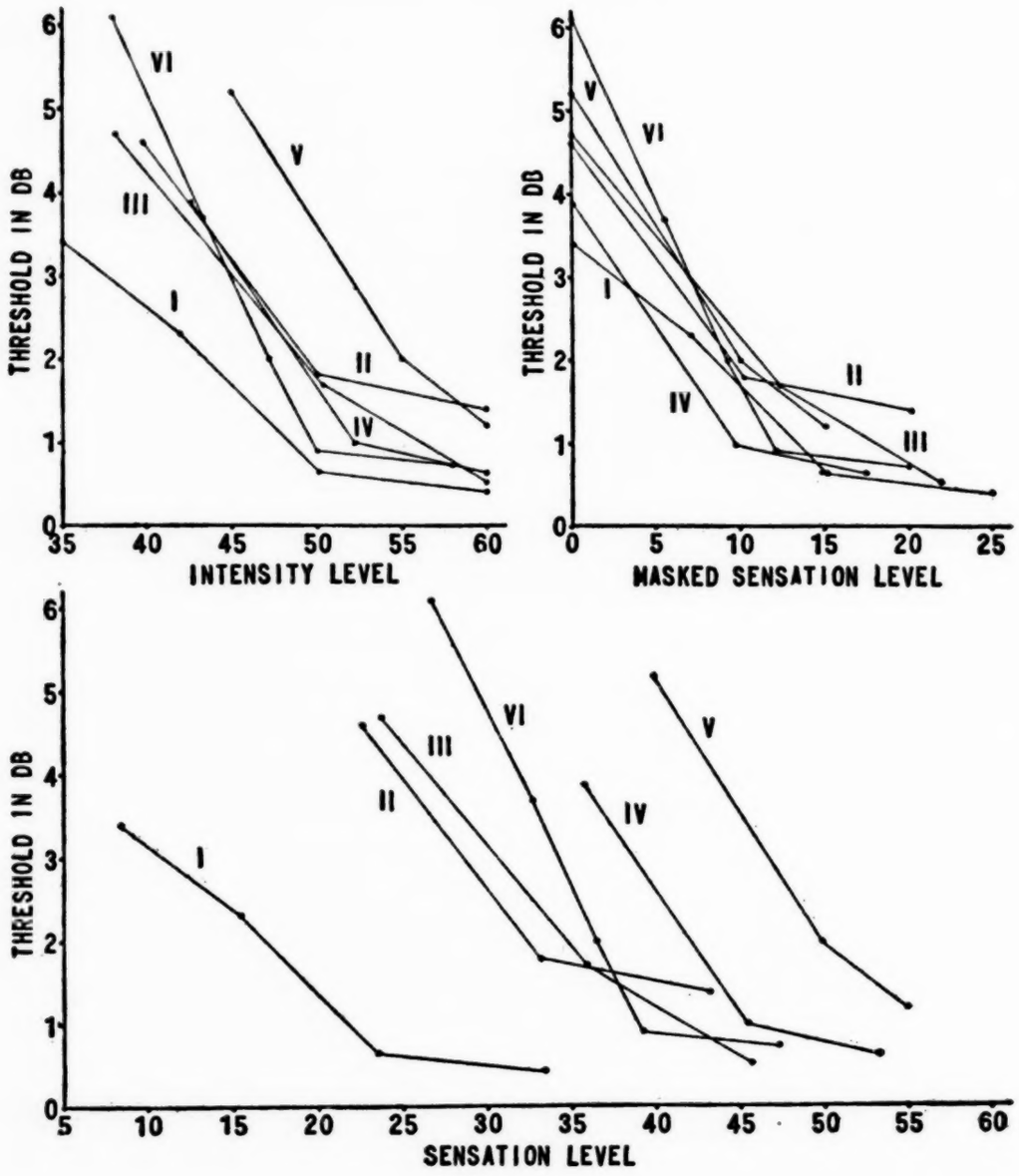

FIG. 9

tionship of m.d.t. to sensation level and that of m.d.t. to masked sensation level. In both cases, the curves for the two observers are similar and are not greatly displaced from each other. However, when the data on all six of the harmonics

are dealt with together, a different conclusion must be drawn. In Fig. 9, all of the data for observer B, on each of the six harmonics, are plotted in the three different ways. There is a curve in each of the three graphs for each of the six harmonics. The curves in the upper right-hand graph have a remarkable degree of coincidence, especially as compared with the curves in the graph at the bottom. If a single function

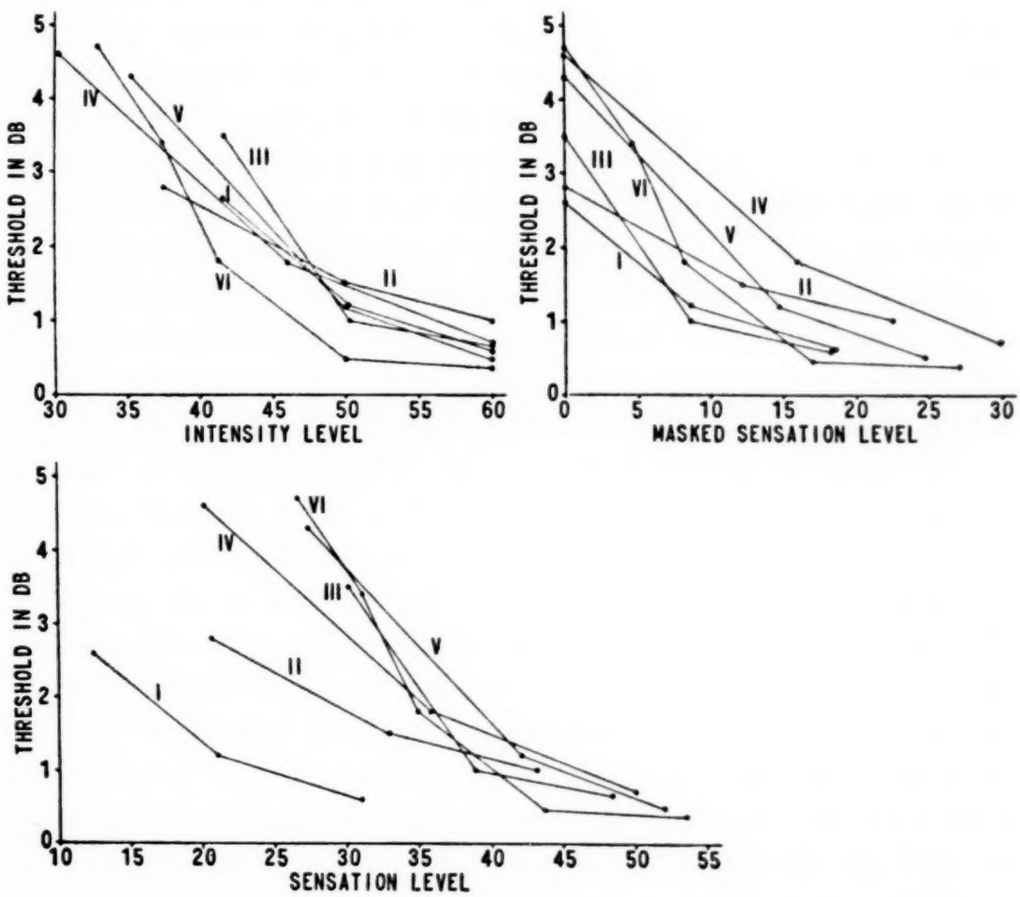

FIG. 10

were to be sought which would tend to describe the relationship between m.d.t.'s and the levels at which they were measured, the variables for the function, in the case of observer B at least, would probably be m.d.t. and masked sensation level.

A somewhat different picture is given by the results on the six harmonics for observer A. These results are plotted in the three different ways in Fig. 10. It will be seen that the curves have the highest degree of coincidence in the upper left-hand

graph, where m.d.t. is plotted against intensity level. Clearly, the relationship between m.d.t. and masked sensation level was less unique for observer A than it was for observer B. The reason for this difference is obscure. It is obvious, in any event, that the relationship between m.d.t. and sensation level was quite remote for both observers.

Regardless of the relationship (or set of relationships) which is finally found to hold between m.d.t. and some measure of the level at which thresholds are determined, the data presented in Figs. 9 and 10 reveal that the m.d.t.'s for the various harmonics decreased in a similar manner. The threshold values secured at levels near the m.a.t.'s were all relatively large, while those secured at levels 15 or 20 db higher were all relatively small. The indication is that the smaller m.d.t.'s, all but three of which were less than 1 db, were quite close to a minimal limit. Of importance in this connection is the fact that typical *thresholds for loudness discrimination*, when pure tones are used as stimuli, fall between about 0.5 and 1 db.

It may be inferred, from the data on m.d.t.'s, that a masked harmonic is not necessarily free from the influence of masking just because it is above its m.a.t. In other words, a masked harmonic may be specifically audible in the presence of a group of masking harmonics and yet not be completely 'unmasked.' An all-inclusive statement on the above-threshold range of partial (or fractional) masking cannot, of course, be given. However, under the conditions of the present experiment, any one of the masked harmonics had to be between 15 and 20 db above its m.a.t. before its m.d.t. was near a minimum; and this fact implies that the range of partial masking was between 15 and 20 db. Further investigation will no doubt reveal that the range is dependent upon the number as well as the frequency and intensity levels of the masking harmonics, and perhaps even the phase angle of the masked harmonic.

The data on m.d.t.'s show that once a masked harmonic was from 15 to 20 db above its m.a.t., relatively small changes in its intensity level were perceptible. A change of less than 1 db was typically detectable. It has already been suggested

that the lower values of m.d.t. were near a minimal limit. This implies that, when any one of the masked harmonics was between 15 and 20 db above its m.a.t., a small change in its intensity level was about as noticeable as it would have been in the absence of masking harmonics. Confirming evidence on this point was secured in a special series of measurements which will now be described.

To avoid the possible influence of stray components in the stimulus on the magnitude of m.d.t.'s, the special measure-

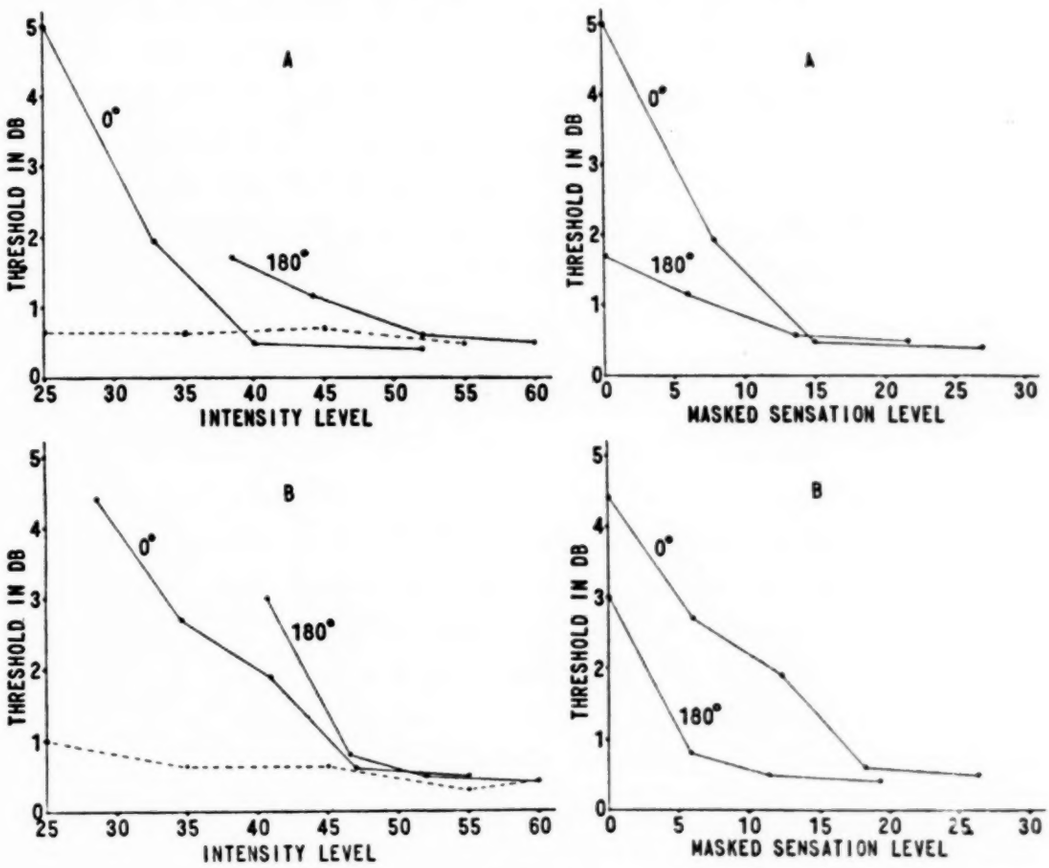

FIG. 11

ments were made on harmonic VII when it was sounded in the presence of harmonics II to VI, inclusive. The stimulus conditions were basically the same as those which prevailed when the m.a.t.'s of harmonic VII were measured in relation to its phase angle. (See Fig. 6.) Masking harmonics II to VI, inclusive, were all in phase and were each set at an intensity level of 60 db. Representative values of m.d.t. were obtained on VII. The results are given in Fig. 11. In this figure,

there are four different graphs, two for each observer. The data for each observer have been plotted in two different ways. The curves labeled 0° are based upon m.d.t.'s which were obtained on VII when its phase angle was 0°. These curves have the expected shape. The curves labeled 180° are for values obtained when VII had a phase angle of 180°. The difference between the two sets of curves points to a relationship between m.d.t. and phase angle, a relationship which probably depends upon the interfering action of subjective harmonics. This finding should not be ignored; but for the present, attention should be given to the broken-line curves in the two left-hand graphs in Fig. 11. These curves are based upon *thresholds for loudness discrimination.* Threshold values were secured at four different intensity levels for observer A, and at five different levels for observer B. The procedure called for presenting harmonic VII alone, in the complete absence of masking. The single harmonic was sounded during both portions of the stimulus period—at a given fixed intensity level during the standard portion and at one of five suitably higher levels during the variable portion. An observer judged whether the loudness of the tone was greater during the first or second half of each stimulus period. The thresholds were computed by means of linear interpolation, the percentage criterion (75 percent) being the same as that used in computing m.a.t.'s and m.d.t.'s. The important thing to note is that, at the higher intensity levels, the curves for m.d.t.'s and for loudness discrimination thresholds practically coincide. Thus, masked harmonic VII is shown to have been partially masked to different degrees over an appreciable range of intensity levels and to have become, at the higher levels, virtually free from the influence of the five masking harmonics. It may be supposed that the finding on VII is at least roughly applicable to the other masked harmonics whose m.d.t.'s have been measured.

A few additional measurements which were made on harmonic VII pointed to a relationship between m.d.t.'s and the intensity level of the masking harmonics. Harmonics II to VI, inclusive, were each set at 40 db.; whereupon, representa-

tive m.d.t.'s for VII were secured. The results for observers A and B, plotted in two different ways, are represented in Fig. 12 by the curves labeled 40. The curves labeled 60 are

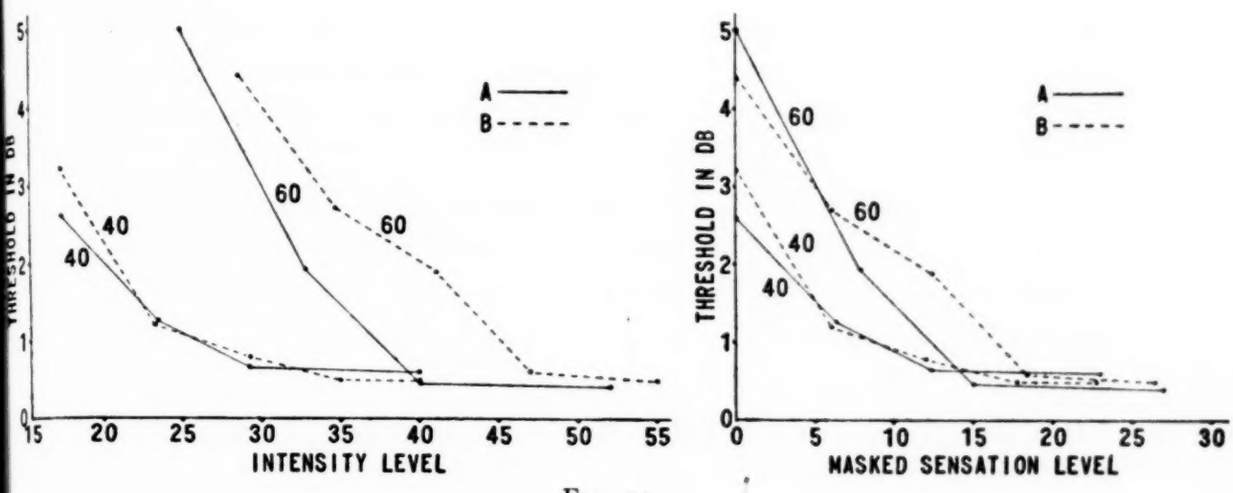

FIG. 12

duplicates of those labeled 0° in Fig. 11. The two sets of curves, especially as they appear in the right-hand graph, are readily seen to be of the same general shape, but they are significantly displaced with respect to each other along the ordinate.[8] In other words, changes in m.d.t. with level above m.a.t. were similar in form, but the m.d.t.'s were consistently lower for the 40-db than for the 60-db setting of the masking harmonics. Further investigation will show, presumably, that there is some type of direct relationship between the magnitude of m.d.t.'s and the intensity level of the masking harmonics.

SUMMARY

Measurements were made of the masked absolute and masked differential thresholds of individual masked harmonics when they were sounded in the presence of a group of masking harmonics. The complex stimuli, which were presented monaurally to the observers through a calibrated receiver, were produced with an electrostatic type generator of special design.

[8] The fact that the two sets of curves in the left-hand graph are displaced with respect to each other along the abscissa means that values of m.a.t. for the two conditions of masking differed by the amounts of the displacement.

The frequency and intensity levels and the relative phases of the various harmonics were subject to control. A modification of the constant process was used in securing the experimental data. Threshold values, computed by linear interpolation, were based upon large numbers of judgments. Two trained observers served throughout. The investigation was far from exhaustive, but the following conclusions seemed justified.

1. The magnitudes of the masked absolute thresholds (m.a.t.'s), with essentially normal sensitivity of the ear, were conditioned by simple masking factors (that is, by 'spread-out patches of disturbance' along the basilar membrane); by the specific interfering action of subjective tones; and perhaps to a limited extent, by the influence of relatively weak *stray* components in the stimulus. The evidence on interference between subjective and objective harmonics was indirect but nevertheless rather convincing. Future investigations of m.a.t.'s should provide, in particular, for a careful survey of interference phenomena.

2. The masked differential thresholds (m.d.t.'s), for any given masked harmonic, decreased markedly in magnitude with increases in the level of the harmonic at which thresholds were measured. The threshold values secured at levels near the m.a.t.'s were all relatively large, while those secured at levels 15 or 20 db higher were all relatively small. When any one of the masked harmonics was around 15 or 20 db above its m.a.t., small changes in its intensity were about as noticeable as they would have been in the complete absence of masking harmonics. A masked harmonic was partially (or fractionally) masked over a considerable range of intensity above its m.a.t., the amount of partial masking decreasing as the level above m.a.t. increased. The amount as well as the total range of partial masking will undoubtedly be found, upon further study, to depend upon the number, frequency level, and intensity level of the masking harmonics, and also upon the relative phase angle of the masked harmonic.

The results of the investigation have a direct bearing, of course, only upon masked thresholds. It is believed, however,

that they will contribute to the solution of problems relating to the definition and analysis of timbre.

(Manuscript received July 2, 1940)

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THE RELATION BETWEEN CORTICAL RESPONSE TO VISUAL STIMULATION AND CHANGES IN THE ALPHA RHYTHM

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The dominant waves in the cortical record of the rabbit vary from about three to five per second, depending upon depth and kind of anesthesia as well as a number of other factors (4 and 7). This range comprises the alpha rhythm, and the rate and amplitude of the waves in it may be manipulated experimentally much in the same way as has been reported for the human electro-encephalogram (E.E.G.).

In the human E.E.G. it has been observed that the alpha rhythm is sensitive to certain broad features of the ordinary environment (6, 8, 9, 11, 12, 13, 14, 15, and 16). The waves tend to disappear upon changing the room from darkness to light, though they may return in some degree if illumination is continued for a matter of seconds. If the eye is confronted with a homogeneous field the result is often a less effective elimination of waves, than if it is patterned.

Though individuals vary greatly, first in the presence or absence of distinct alpha waves, and secondly in the conditions effective in manipulating them, the fact that the waves can be manipulated has led to speculation about the mechanism involved, or to say it differently, as to what the waves represent.

It has become customary to speak of the alpha rhythm being *blocked* by the conditions that happen to cause its disappearance (6, 8, 11, 12). Blocking or inhibition necessarily connotes the cessation of something. If in this case it merely implies the cessation of observable waves in the record, the

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term may be permissible. If it implies the cessation of activity of the cells involved in producing the waves, the interpretation is not yet supported by fact. Indeed all of the evidence of this laboratory suggests that the disappearance of the waves simply indicates the onset of a different temporal sequence among the active elements rather than the cessation of their activity.

In the rabbit, the cortical electrogram changes when the room illumination is sufficiently altered, much as does the human E.E.G. This animal provides for accomplishing the purpose of the present study; namely, to go beyond the mere demonstration of the change produced by the gross shifts in environmental conditions, and show what takes place when the alpha rhythm is affected in a specific way.

On the basis of the fact that steady light reduces the size of the alpha waves, it could be expected that flashes might do the same, and leave the cortical picture uncomplicated by them, whereupon one could observe the specific responses to the flashes themselves. But it will be found that this is not what actually takes place. We are left to judge whether the particular combinations of responses and spontaneous alpha waves are simply algebraic summations of the two separate trains of events in the record, or whether the mechanisms back of the two phenomena actually influence each other.

Method

The method consists in confronting the animal eye with a series of flashes at rates ranging from 1 or 2 per second to a rate double or treble the alpha rhythm. In the result, two principle events then follow: a change occurs in the rate and size of the waves in the alpha rhythm depending on the stimulus conditions impressed on the animal, and also specific responses follow the flashes.

In considering method, it is well to know what the components of a complete response to a flash of light are. The first deflection, surface-positive, is rather spike-like and may or may not be greater in amplitude than the prevailing alpha waves. If it emerges in the electrogram on the crest of an alpha wave, it is prominent. The first negative phase of the response is a more prolonged wave, having much more nearly the time characteristics of an alpha wave than does the first component. A third deflection is positive and also prolonged. Consequently the first part of the response can be easily differentiated from alpha waves while the later components are quite similar to them.

The cortical response to direct electrical stimulation of the optic nerve serves as a good standard of comparison for besides being complete its components stand out more

boldly. Electrical stimulation can be made strong and very brief at the same time, activating the fibres of the whole nerve, each discharging but one impulse. Such an input produces a response consisting of three main deflections, a brief surface-positive excursion, a more prolonged negative one, and a final broad positive one. The first of these has been analyzed into a number of parts, but taken as a whole, it may be considered as the specific visual response. The third deflection as in the case of photic stimulation has the proportions of an alpha wave, and both may be so considered.

A stimulus then elicits a specific visual response which in turn is followed by one or *more* alpha waves since the train of events following a single electric shock was often seen to consist in a number of regularly spaced large waves (4). One of the important features to be pointed out is that to affect an alpha wave, the phenomenon in question must occur at a time represented by the cycle before it. That which appears in the record as a specific response spike upon an alpha wave is simply an algebraic summation in the record. For the diminution, enhancement or other change of a given alpha wave, we must look to events which occurred during the previous cycle.

This description applies to single or isolated responses, while it is to be recognized that rapidly repeated flashes may elicit responses which are, to all appearances, incomplete.

Results

Animal A

In the case of this animal as in a number of other experiments, records of the cortical response and alpha activity were made with the flash rate at a number of settings. As the rate was progressively increased from 1.2 to 10.7 per second in fifteen steps, significant differences in outcome were observed which seemed to indicate beyond question the interaction between the response and the spontaneous activity. Flashes at 1.2 per second reduced the amplitude of the dominant 4 per second alpha to half size. Each flash was well responded to, and included the later long negative deflection as well as the first positive peak. As the flash rate was raised, the height of the alpha waves became less affected. Flashes at 4 per second, the then existing alpha rate, accentuated and made it more regular. By the time that the flashes had reached 5.45 per second, irregularity of pattern again became pronounced. Later, when 6 flashes per second were delivered their rate was about twice the rate of the alpha rhythm exhibited before their onset. Each flash elicited a response, the series having the appearance of a row of very narrow saw teeth. The waves, though taken to include responses, had the appearance of alpha waves speeded-up to nearly double rate and sharpened somewhat. They had much the same shape and regularity as those produced when flashes were delivered at 4 per second.

The onset of the flashes delivered at 6.7 per second threw the waves of the record into confusion for a time. Subsequently, large regular waves which appeared to be the responses emerged. Their rate indicated that they were responses to every second flash, their shape showing that they included some alpha activity.

The series of 8.4 flashes per second elicited a definite response only to alternate flashes, this result alternating with the interference periods during which the alpha-like waves were lower than before the flash series was applied, though during synchrony they were much higher.

With 10.7 flashes per second alternate flashes were represented by definite responses which were combinations of spontaneous waves and the regular response spikes. The responses alternated in size, the large ones presumably appearing during the excitable phase of the alpha cycle. Periodically, however, since the synchrony was only approximate, interference set in.

Animal B

This animal was possibly less under the influence of ether, if our suppositions are correct, for there was a more marked difference between the records taken with the room light on and those taken in darkness.

The other and much more outstanding symptomatic difference between the two animals indicating the same thing was the fact that, at the higher flash rates, the records showed definite responses to consecutive flashes rather than to alternate ones. (See Fig. 1.) When the responses followed each flash at a rate of about 10 per second, their amplitude was very greatly reduced. The record consisted in a tiny regular ripple superimposed on irregular long slow changes in the level of the base-line. Periodically the ripples virtually disappeared.

In this figure, one is also able to see the difference between the spontaneous activity with the room light on (first line) and the room dark just prior to stimulation (beginning of second line). Steady light tends to reduce the amplitude of the alpha waves.

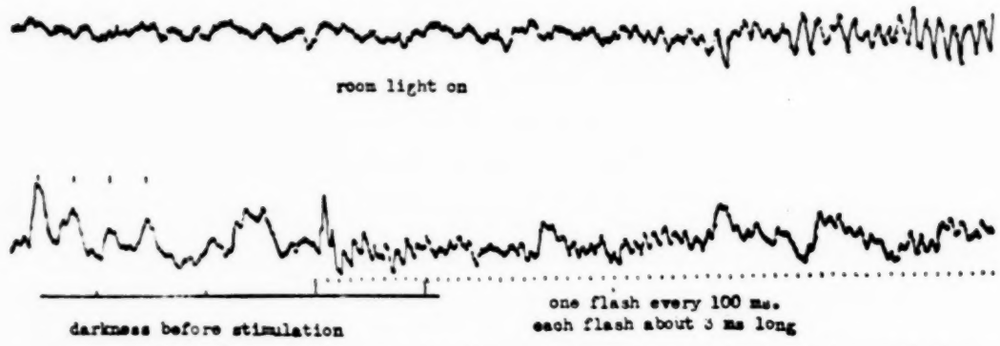

FIG. 1. This figure illustrates the difference between cortical activity with the eye illuminated (top record) and in the dark (first part of second record), and also the modification produced by a rapid sequence of flashes (approximately 10 per second). Flashes are indicated by dots, seconds by marks on the line, and the alpha rhythm above the waves in the second record. This figure demonstrates (1) depression of alpha by general illumination; (2) diminution of alpha by a series of flashes; (3) ability to respond to rapidly repeated flashes.

Animal C

A record from this animal, shown in Fig. 2, depicts the *on*- and *off*-responses to long flashes when the light-dark-ratio was 1 : 4. It will be noted that the immediate response waves and their sequelae dominate the whole record, obliterating

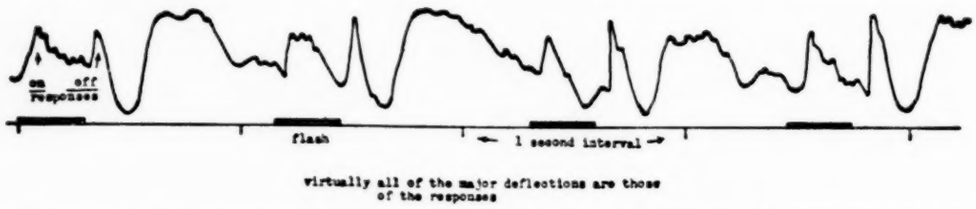

FIG. 2. This record shows a case in which the total activity is represented by the response of the cortex to repeated stimulation. The *off*-response is more complete than the *on*-response.

the particular train of alpha waves which characterized it just prior to stimulation. The huge positive deflections following the *off*-responses are excellent examples of the third component of a complete response. Here it will be noted that is the *off*-response which produces them. This means that the *off*-response produces the same kind of alpha activity as the *on*-response, except in different elements (3).

Animal D

Three records from this animal are shown in Fig. 3. The top one indicates a slow flash series almost obliterating the

alpha waves. They do tend, however, to regain some of their original size after a time.

The second line shows a case in which the alpha cycle tended to retain more nearly its original characteristics during

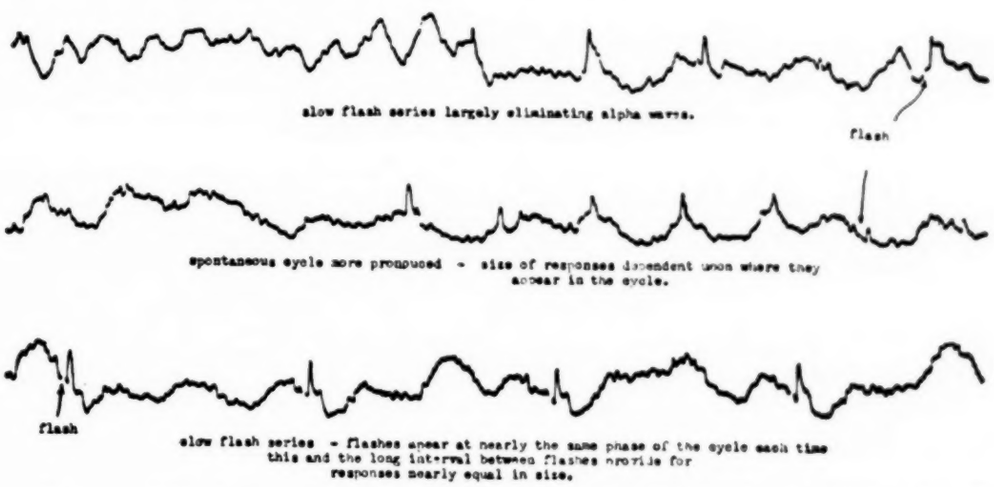
slow flash series largely eliminating alpha waves.
flash
spontaneous cycle more pronounced - size of responses dependent upon where they appear in the cycle.
flash
slow flash series - flashes appear at nearly the same phase of the cycle each time this and the long interval between flashes provide for responses nearly equal in size.

FIG. 3. The features illustrated here are indicated in the figure itself. The breaks in the line are made by huge deflections of the photronic cell used to indicate location and duration of the flashes. Flashes in bottom record are 870 milliseconds apart.

stimulation. This and the top record both show that the size of the response is dependent upon the phase of the alpha cycle in which the stimulus appears. When the flash is at a critical point near the peak of an alpha wave the response spike is at its maximum. If much earlier or later, it is much smaller. Since the alpha waves are not perfectly regular either in temporal separation or in contour, many exceptions to this may seem to occur, but when all things are taken into account this statement holds.

The bottom line shows a much slower flash rate (870 milliseconds between flashes). Due to this and the fact that the flashes all appear in about the same phase of the alpha cycle, the responses are approximately equal.

This animal represents certain other features also. (See Fig. 4.) Record *A* is a case in which flashes were delivered during a time in which the alpha waves were very inconspicuous. Under such conditions, response to the flash series is pronounced. Note the four large waves to the four flashes. Their conformation is much like those of the usual alpha

waves. Record *B* shows another short series of flashes occurring while the alpha picture is more pronounced than in *A*. The result is a more irregular series of responses, indicating some conflict or competition between the stimuli and the in-

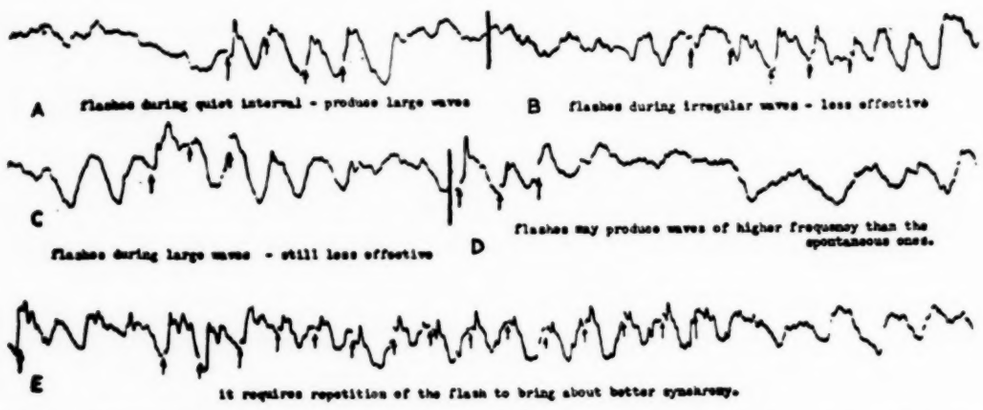

FIG. 4. Records partially explained in figure. Arrows indicate location of breaks in line where flashes fell. Flash rate in all is about 6 per second.

trinsic activity. Record *C* shows the results of three flashes delivered during a time when the intrinsic alpha waves were very large. In this case the responses were relatively inconspicuous. On the assumption that the spontaneous activity (alpha) and the specific response employ the same pathways, or that one pathway affects the other, the diminutive size of the latter may be due to the usurpation of available elements.

Record *D* shows the responses to three flashes. They are the last three of a longer series and the repetitive rate marked off by them is very much faster than the spontaneous waves which follow.

Record *E* shows about the same thing as *D*, but not to such a marked degree. The series of flashes is long, and during its course somewhat better synchrony of responding elements is undoubtedly brought about as evidenced by the increasing regularity of the waves.

Animal E

In Fig. 5, another very forceful way of showing the activity of elements involved in the spontaneous waves and in the response is represented. It consists in a series of four records, showing the responses to paired flashes delivered 70, 90, 137,

and 195 milliseconds apart. In this series, as well as in previous records, two features are of concern—the response and the way stimulation alters the spontaneous activity.

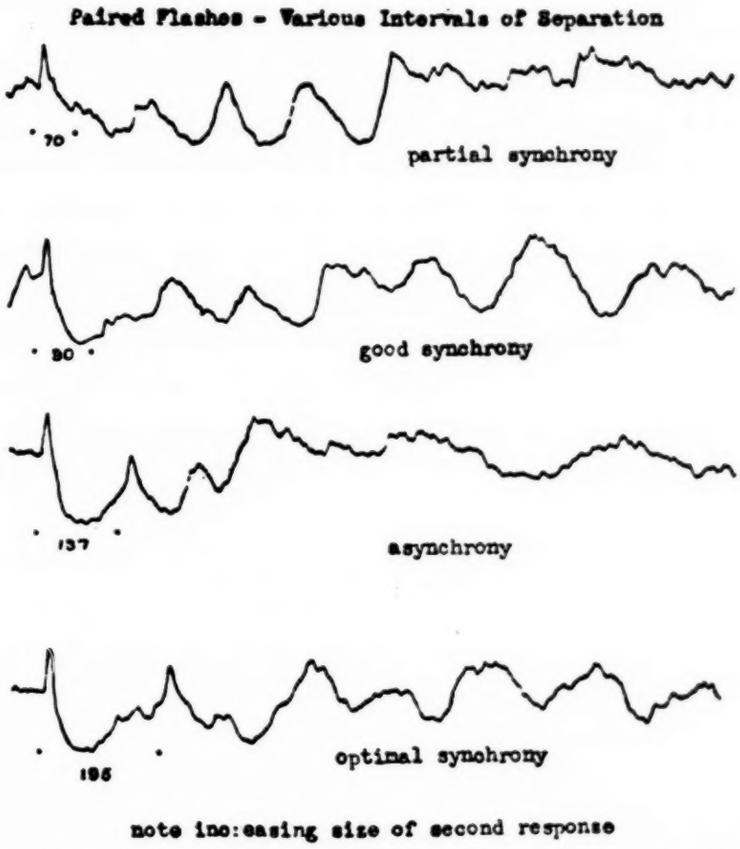

FIG. 5. Records partially explained in figure. Dots indicate location of flashes; numbers, the separation in milliseconds. See text for further explanation.

It is obvious that the response to the second flash is ineffective unless sufficient time is allowed between flashes. This at a minimum is in the neighborhood of 90 milliseconds, a value quite like that found when using paired electric shocks to the optic nerve, though it is a different minimal interval than happens to be effective in producing fair-sized responses to repeated stimulation. The possible reason for this has already been discussed (**2**) and will be referred to a little later.

It will be noted that the events following the responses are not alike in all cases. The records following the 90 and the 195 milliseconds intervals are quite similar, while the other two are different but match each other fairly well. The period represented from crest to crest in the wave train following the

195 milliseconds interval is quite like the flash interval itself. The second flash happened to have been delivered at such a time as to fit into the intrinsic periodicity of the system, producing a full-sized response and helping maintain the alpha wave train.

The 90 milliseconds interval was about twice the alpha rate and the pair of flashes were able also to do about the same as the 195 milliseconds pair regarding the alpha waves, though the second was barely able to produce a specific response. The second flash in each of the other two pairs (70 and 137 milliseconds) is out of phase with the intrinsic rhythm and the same continued series of alpha waves does not appear in the record. The second flash of the 70 milliseconds pair interferes less than does the second of the 137 milliseconds pair, as would be expected.

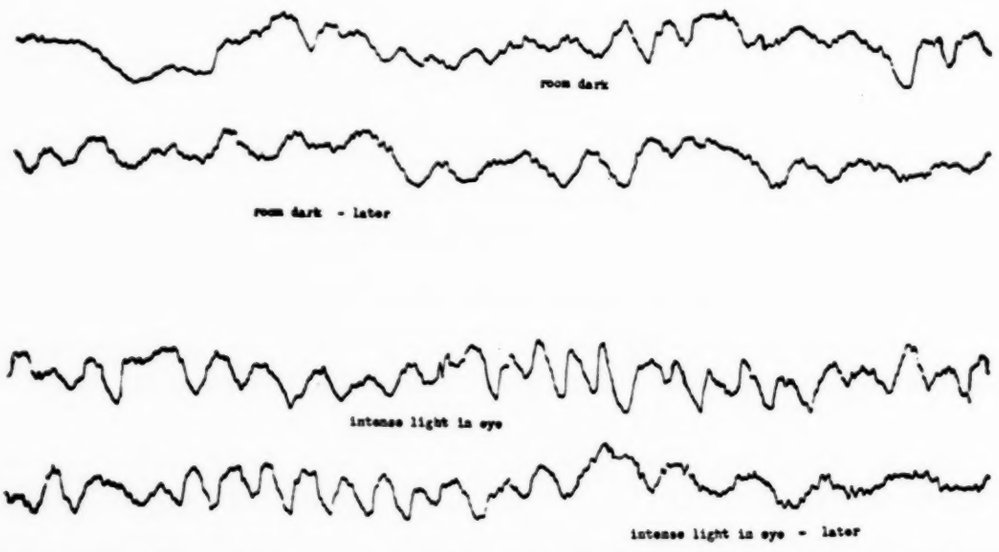

FIG. 6. This figure is a comparison of cortical activity under conditions of darkness and very intense illumination (18,000 c/ft^2).

In Fig. 6, a comparison between darkness and very intense illumination (18,000 c/ft^2) is shown. Our previous comparison between cortical activity during the retinal illumination and darkness involved only ordinary room intensities. The outcome was a diminution or temporary abolition of the alpha rhythm. From the appearance of enhanced alpha waves, it seems as though intense stimulation operates in the direction of synchronizing cortical elements. This is similar to the

findings while using intense stimulation upon the *Dytiscus* visual system (1), for the interpretation of which results the notion of synchrony was employed.

Animal F

For this animal, a series of long flashes delivered every 715 milliseconds is shown in Fig. 7. The light-dark-ratio is

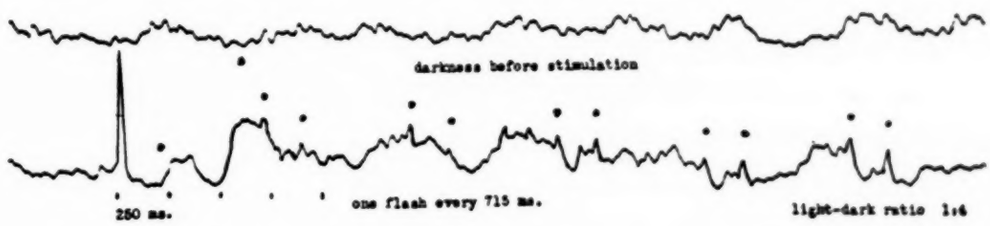

FIG. 7. The two lines are two parts of a continuous recording and show that a flash series may augment the amplitude of the major waves, at least superficially, simulating the enhancement of the alpha rhythm. The first *on*-response is huge. Dots below the line indicate time; those above, location of *on*- and *off*-responses.

1 : 4, as in Fig. 2, but the outcome is somewhat different. The responses are smaller and do not eclipse the other features of the record. If anything, the alpha ryhthm seems to be enhanced over what it was prior to the flash series. The first *on*-response is huge but the following ones are much smaller. In fact no *off*-response is obvious following the first *on*, and the next pair of *on*- and *off*-responses is very small. They increase in size upon repetition, and hand-in-hand with this is a smoothing out of the spontaneous part of the record.

DISCUSSION

From results such as we have both described and documented with records, it is clear that the alpha rhythm and the specific cortical response to incoming excitation from the sensory periphery greatly influence each other.

In the first place, the effect of stimulation by light may be either of two extremes, either to 'abolish' or 'induce' synchronized alpha activity. The result is determined by the time distribution of the stimulus, by its intensity.

Only infrequently does a cortical pattern displaying alpha waves cease to exhibit them during a series of discrete light

flashes applied to the eye. The more usual occurrence is the enhancement of them if they already exist or the institution of them if they are previously absent.

It is most usual for a single bright flash to institute a train of alpha waves. Originally these were considered a part of a complete response (4). Two flashes separated by a critical interval are also able to elicit a train of alpha waves or accentuate feeble ones. This critical interval is the time represented between the peaks of two adjacent alpha waves. A nultiple or submultiple of this interval produces effects quite in keeping with expectations.

The first flash of a series may happen to be delivered at such a time that the resulting excitation is out of phase with the spontaneous cycle. If the flash is weak it utilizes such elements as are available on the basis of threshold and degree of concurrence of phase. If it is intense, it is often able to elicit a large response due to the fact that high threshold is no obstacle and it is also able to break through a greater portion of the refractory phase of the cycle. It may thus be able to collect a considerable mass of elements into a single phase of activity. But if the cortex happens already to exhibit a marked alpha rhythm, the response will not be large for it is as if most elements are already occupied spontaneously and but few elements are left to be used by experimentally produced exictation of any strength. Thus, even if the flash is timed so as to fall at the most opportune instant, the huge wave or waves resulting can not be said to represent specific responses but are in a large part to be credited to the alpha cycle. The shape of the waves will indicate a predominating alpha component, and will be essentially different than the large deflections of vigorous specific responses.

Regardless of where the first flash of a series falls, repetition will tend to alter results. The shifts in wave pattern which result are seldom the mere algebraic addition of two sets of waves of different frequencies as they slide past each other in the record, but are temporary irregularities from which emerges a new outcome. This may be either a train of quite regular waves (3) whose rate is that of the flash

series, a train whose waves represent only every second or less frequent flash, a diminished alpha and a train of responses, or else an accentuated alpha into which the specific response series is mixed.

Finally, since a steady light is the limit of a high frequency series of discrete flashes, the result of steady stimulation in 'abolishing' the alpha rhythm must be the same as the result of flashes repeated with sufficiently high frequency. Since it is demonstrated that light stimuli can induce the alpha rhythm in the record as well as cause it to disappear, it can be inferred that steady illumination, resulting in unsynchronized retinal activity, will set up unsynchronized alpha activity in the cortex. This activity must fail to appear in the cortical record to the degree to which it is unsynchronized. That is to say, all alpha activity is not observed in the record. Due to the possibility that the elements involved in the type of cyclic activity ordinarily observed can become divided into lesser groups greatly out of phase with each other, the alpha or any other activity can as well produce a straight line as a train of undulations in the records. This is an important point, and from this the deduction is made that 'blocking' is of this sort rather than a cessation of activity.

It is now clear that a distinction needs to be drawn between alpha activity and the alpha rhythm. The former is the activity which, if not masked by other activity of opposite sign, would appear in the record as the familiar undulations. The latter, the alpha rhythm, is the same activity, as far as the individual elements are concerned, which is able to produce the well known waves in the record, due to the fact that the preponderance of the spontaneous activity is in the same phase.

That the result of intermittent stimulation is not only a series of specific spike-like responses, but the creation of an alpha rhythm where it did not exist before, the accentuation or abolishment of an existing alpha train, or the alteration of its wave frequency leads us to consider not only the question of blocking brought up by use of uniform illumination, but to examine the applicability of the terms, *adaptation* and *facilita-*

tion, which have come to be used in the literature on the alpha rhythm (**5**).

Since the alpha rhythm as a pattern is the outcome of a particular temporal distribution among the elements responsible for the cortical record, rather than the actual number of elements involved, the terms facilitation and adaptation, as used in the literature with reference to the rhythm, do not apply except perhaps very superficially. These terms fall into the same category as does blocking. In order that facilitation apply to the rhythm it would have to be shown that when it exists a greater number of units are integrated into the activity than otherwise, producing a greater end-result, or a speeding-up of the ultimate outcome. For adaptation to apply in the strict neurological sense, it would have to be shown that the disappearance or reappearance of the alpha rhythm depended primarily upon an internal change in the elements involved. While it is true that neither all facilitation nor all adaptation is neurological, neural phenomena are dealt with here and descriptions and explanations should be put into neural terms.

Though it is to be granted that in the continued activity of any large mass of cells, facilitation and adaptation (used in the neural sense) do occur, it has not yet been shown that these mechanisms are at the bottom of the appearance or disappearance of the alpha waves.

That the alpha-like waves can be speeded-up as a result of properly timed retinal stimulation may, however, be a real example of facilitation (**8** and present work). The rate of the alpha rhythm is not fixed, and its fluctuations may be the result of convergence of a variable number of impulses upon critical neurones, or else a change in the state of certain neurones due to more general causes. It follows, however, from what has already been said about the alpha activity, that certain ranges in frequencies might be due to the staggering two or more separate rhythms.

As far as we can tell, no adaptation is represented by any aspect of the alpha rhythm records.

The work in this laboratory has dealt, from time to time,

with several aspects of cortical response; namely, its spontaneous features including the alpha rhythm, the effectiveness of the second of two supra-liminal peripheral stimuli, the results of repeated stimulation, the summation of two subliminal peripheral stimuli, and the effect of drugs on these features.

It has become more and more clear that in such cases we are dealing with two groups of cells, one expressed in the specific cortical response to peripheral stimulation, and the other represented in the alpha rhythm. The second group is spontaneously active, but the first is not. Strychnine differentially affects the two groups, spontaneous activity disappearing while certain components of the specific response are enhanced.

Normally the two groups interact. A specific response tends to set up an alpha train, while the size of a specific response to an isolated stimulus is dependent in part upon its temporal relation to the alpha cycle. Under strychnine topically applied to the cortex the specific response, though greater in size, no longer induces an alpha train. This is not simply the result of a severed connection between the response and spontaneous groups, for alpha waves no longer appear spontaneously. Repetitiousness produced by localized strychnine is expressed in the activity of the non-rhythmic elements responsible for the specific response.

Effectiveness of repeated stimulation is dependent not only upon the place in the alpha rhythm (spontaneous excitability cycle) each stimulus falls, but also the spacing of stimulation and the extent of its repetition. This is not due to refractoriness in any single element such as a synapse but to factors involving much more time. Since the interval is a measurement of the time between response of a functional unit (possibly a chain) and its ability to respond again either partially or to full extent, the determiner of this factor lies in the elements essential for a complete response. This brings up the question of how the spontaneous activity is linked into the response chain since we find interaction between the two.

That the refractory interval between two effective stimuli

is greatly reduced after repetition of stimulation suggests that the second stimulus of a pair following in the wake of the activity produced by the first is able to selectively re-activate functional units which have the shortest refractory period and have sufficiently recovered. Out of the group of parallel chain units some are ready to be re-activated much sooner than others. The first stimulus arriving utilizes these, and just to that extent throws the group out of its original synchrony, but the principle provides for response to flashes spaced much more closely than at the outset of the series. After a few repetitions, flashes, though very rapidly repeated, may elicit responses, each nearly equal in size, but much smaller than the response to the first stimulus, the size being accounted for by supponing that the reaction of the total number of units is distributed among several successive stimuli.

Each of the responses though closely spaced tends to be followed by its alpha wave in the record while the rate of repetition is still not high and when there is no algebraic clash. Thus the records often contain not only rapidly repeated specific responses but alpha waves at much higher rates than prior to stimulation.

This principle accounts for the effectiveness of steady illumination, it being the terminal case in the frequency range.

Summary

Electrograms of the rabbit's optic cortex when the eye was intermittently stimulated with light were examined to determine the modifications of the alpha rhythm.

The records as well as all previous though incidental information pertinent to the subject indicate that two different groups of elements are responsible for two of the salient features of the cortical electrogram. The activity of one group is expressed in the specific cortical response ('visual') to peripheral stimulation and the other in the later components of the complete outcome of stimulation. It is the activity of the latter group that is manifest in the alpha rhythm. The two groups interact.

Blocking of the alpha rhythm is not a matter of inhibiting

the activity of the alpha elements but rather temporally dispersing their activity-rest cycles. The use of the term adaptation in the neural sense is not justified in describing the salient features of the alpha rhythm changes which we have found or are reported in the literature.

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SOME RELATIONSHIPS BETWEEN ELECTRICAL SIGNS OF CENTRAL AND PERIPHERAL ACTIVITY: I. DURING REST[1, 2]

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Three theoretical positions are available to those who attempt to present physiological correlates of 'mental' activity. The first position is one of long experimental standing, that which postulates a close if not an exact correspondence between peripheral (muscular) activity and 'mental' phenomena. The second position is one of equally long standing (although precise, experimental approaches are fairly modern), that which postulates a close if not an exact correspondence between central (cerebral) activity and 'mental' phenomena. The third position is one which straddles the fence, so to speak, and sees 'mental' phenomena as a total organismic process involving both central and peripheral physiological mechanisms.

The bolstering of all these viewpoints has become easier with the development of modern electrophysiological techniques which enable the investigator to record fairly localized physiological phenomena, in the intact human organism, under a veriety of controlled laboratory conditions.

Several investigators have used electrophysiological techniques in the study of the relationship between 'mental' activity and peripheral activity. These workers have presented a considerable body of evidence indicating that mus-

[1] This study is the first of a series of papers bearing upon this general topic under the direction of Dr. John R. Knott in the laboratories of the Department of Psychology in the State University of Iowa.

[2] The main content of Part I of a dissertation submitted in partial fulfillment of the requirements for the Degree of Doctor of Philosophy in the Department of Psychology in the Graduate College of the University of Iowa.

[3] The author wishes to express his gratitude to Dr. John R. Knott, who directed this research.

cular activity accompanies 'mental' (symbolic) activity (**4, 5, 6, 7, 8, 9, 10, 11, 12, 19, 28, 29, 30, 31**).

Following the introduction of the electroencephalographic technique by Berger (**3**), there have been numerous studies which indicate changes in cortical activity record when the subject is engaged in 'mental' or psychological (symbolic) activity (**1, 2, 15, 16, 20, 21, 22, 23, 24, 25, 27, 28, 32, 33, 34, 35, 36, 37**).

Some data exist which bear upon the relationship between cardiac activity and other signs of bodily activity. The heart beat may accelerate, in some cases extremely, during physical activity (**18**) and there is some indication (**17**) that the heart rate is faster during problem solving. Since in 'mental' activity heart rate changes may be inferred to have a cortical origin (at least in part) the electrocardiogram may be considered a measure of central activity, as well as a measure of general bodily activity.

The 'central-peripheral' theory, which the workers in this laboratory favor, in its general outline at least, has been strongly advanced by Freeman (**13, 14**), although we tend to depart from his point of major emphasis. Freeman has proposed a rather inclusive hypothesis which is designed to 'explain' the co-relation between 'mental' and physiological phenomena—the hypothesis of the 'postural substrate.' According to this hypothesis central physiological, or 'mental,' events are determined by peripheral processes, the most notable of which are proprioceptive in nature. Direct measurement of the electrical signs of cortical activity has been made during the experimental alteration of peripheral process by Knott (**23**) who found that increased muscular tension (increased 'proprioceptive backflow,' to use Freeman's phrase) decreased the latent time of blocking of the alpha rhythm, but that the peripheral process did not account for all alterations noted.

Problem

Since the results of previous studies concerned with peripheral change during psychological activity are more stimulating than final and since certain quantitative measures of cerebral

activity are now available, it seems pertinent to inquire into the relationship between electrical signs of central and peripheral activity. Since the present study was designed to be exploratory in nature it was felt that it should not be complicated by the introduction of more than a minimum of psychological activity. It was not expected to present conclusive or final evidence, but to provide a point of experimental departure and to open up possible avenues for further research.

The issues of such an investigation may be stated as follows: what is the relationship between changes in electrocardiographic rate (a quantitative measure of general bodily and also cerebral activity), changes in the amplitude of muscle potentials (a quantitative measure of peripheral activity) and changes in brain potential amplitude and frequency (quantitative measures of cortical activity)?

These issues are concerned with the testing of posited relationships between central and peripheral activity when the index of central activity is physiological and as such is amenable to quantitative measurement similar to the measurement of peripheral activity. An initial test of the predictive value of the hypothesis of the postural substrate is thus possible.

Apparatus and Procedure

Electroencephalograms from the precentral and occipital areas, the electrocardiogram (lead I) and the electromyogram from the left forearm were recorded simultaneously. The electrodes for the cortical records were flattened lead discs about five millimeters in diameter which were attached to the scalp with collodion. The occipital leads were attached to the left occiput and the precentral leads to the right precentral area. The 'indifferent' electrodes were attached in parallel to the two ears.

Similar discs were used as active electrodes for the muscle potential records and were attached with collodion directly above the motor point of the extensor digitorum communis on the dorsal surface of the left forearm. The 'indifferent' electrode was a large zinc plate molded to fit the upper arm and held firmly in place with rubber bands. This is essentially the same electrode placement as that used by R. C. Davis (8).

The electrocardiogram was recorded from two screw-head electrodes, one placed on each wrist.

All placements were kept constant throughout and all electrodes were thoroughly moistened with electrocardiographic paste in order to insure satisfactory contact.

The leads were connected by shielded cable to four, four-stage resistance-capacitance-coupled, high-gain amplifiers (muscle potential time constant, .0025 sec.; electrocardiogram time constant, .25 sec.; brain potential time constant, .67 sec.) and four special four-tube impedance-matching amplifiers. The two electroencephalograms

and the electrocardiogram were recorded on a Grass four-element ink-writing oscillograph. The muscle potentials were recorded photographically on sensitized paper by means of a Westinghouse multi-element oscillograph.

The brain potentials and the electrocardiogram were recorded continuously for about ten minutes while the subject lay comfortably in a dark electrostatically shielded room which was adjacent to the recording room. No systematic relaxation was attempted and no stimulation of any kind was given. After the subject had been allowed to become accustomed to his surroundings, two samples of muscle potentials of 10 to 15 seconds duration were recorded. These were separated in time by three minutes. A signal key was so arranged that the duration of each sample of muscle action potential could be marked simultaneously on ink and film records. Since the Grass writer ran at a constant speed (30 mm per sec.) and a 60 cycle time line was recorded on the sensitized paper, simultaneous analyses of the electroencephalograms, the electrocardiogram and the electromyogram could easily be made.

Twenty adults, five females and fifteen males, served as subjects. Seventeen of these individuals were recorded on two separate occasions, making a total of thirty-seven recordings and seventy-six samples. In all, there were approximately 900 seconds of simultaneous recording.

Analysis of Data

The brain records were read second by second in terms of *amplitude* and *waves per second.*

The measure of *waves per second* will be referred to occasionally as frequency, but it is not actually an average frequency. The reliability of reading, which was determined by rereading 100 seconds of unmarked record, was .89. (Fig. 1*a* shows method of counting waves.)

The amplitude was ready by taking the average amplitude of the three highest waves in each second. This, again, does not provide a true average amplitude but it does give a measure of the amplitude of the brain potentials which correlates .85 with wave-by-wave amplitude measurements. (The method of amplitude measurement is demonstrated in Fig. 1*b*.)

The amplitude for each second of the muscle potential record was read and computed by the same method as that used for brain potential amplitude (Fig. 1*d*) which is similar to the method described by Davis (**9**, **10**). The reliability of reading was .97.

The electrocardiogram rate was obtained for each second in terms of percentage of intersystolic time. This was then translated into beats per minute for a given second (Fig. 1*c*). The reliability of reading was .98.

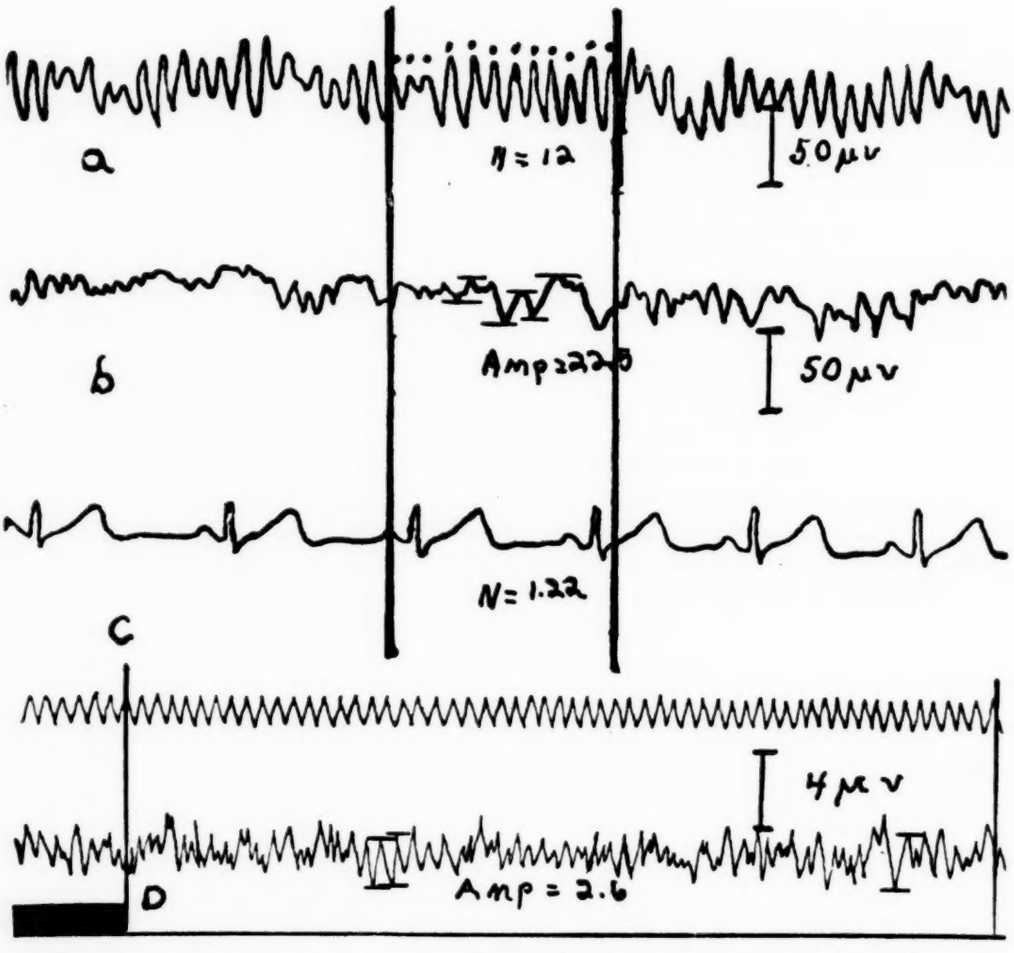

FIG. 1. Representative samples of records illustrating the methods of reading which are discussed in the text. *a*. Frequency of cortical potentials (in waves per second). *b*. Amplitude of cortical potentials (in microvolts). *c*. Rate of heart (beats per second). *d*. Amplitude of muscle potentials (in microvolts).

Some indication of the reliability of the sampling technique may be gained from Table 1.

TABLE 1

COEFFICIENTS OF CORRELATION BETWEEN TWO MEASURES OF THE SAME PHYSIOLOGIC ACTIVITY

	Intervals of 3 Minutes		Intervals of from 3 to 10 Weeks	
	r	*PE*	*r*	*PE*
Occipital Amplitude	.86	.03	.48	.13
Motor Amplitude	.81	.05	.01	.17
Occipital Frequency	.51	.09	.61	.11
Motor Frequency	.60	.08	.42	.12
Muscle Amplitude	.71	.07	.03	.17
Heart Rate	.93	.02	.71	.08

Column one shows correlations, for each variable, between the first and second samples taken in the same experimental run. These samples were separated in time by three minutes. The values of these *r*'s are reasonably high in the case of the brain potential amplitudes and the heart rate. They are lower in the case of the brain potential frequencies and the muscle amplitude. This may be taken to mean that a fair amount of variability in these measures exists from minute to minute.

The third column gives a further indication of the reliability, as well as some measure of the constancy of the variables from one day to another. These correlations are between the average values of the first samples of the first and second runs, which were separated in time by from three to ten weeks. Such low correlations do not affect the interpretation of the results as reported in this study which is concerned, essentially, with changes occurring simultaneously in the various records, although they are interesting in and of themselves.

The data, after having been obtained in terms of average *waves per second* and amplitudes, were treated in two ways. First, correlations were computed between the various recorded variables using the total 900 seconds of simultaneous recording. Second, correlations were computed for each individual subject between the various recorded variables in order to determine to what extent the relationships indicated in the first (gross) correlations were due to individual cases and to see what individual differences appeared to exist.

Results

Table 2 presents correlations which were computed between the six recorded variables (occipital frequency, occipital amplitude, motor frequency, motor amplitude, muscle potential amplitude and heart rate) on the total 900 seconds of simultaneous recording. The correlations between motor and occipital amplitude (.49) and motor and occipital frequency (.42) appear significant, indicating that some relationship exists between the functioning of these two areas of

TABLE 2

SECOND BY SECOND CORRELATIONS * BASED ON 900 SECONDS OF SIMULTANEOUS RECORDING (SUBJECTS = 20)

	Motor Amplitude	Occipital Frequency	Motor Frequency	Muscle Amplitude	Heart Rate
Occipital Amplitude	.49 (*PE* = .017)	−.50 (*PE* = .017)	−.08 (*PE* = .022)	.33 (*PE* = .019)	
Motor Amplitude		−.38 (*PE* = .019)	−.09 (*PE* = .022)	.33 (*PE* = .019)	
Occipital Frequency			.42 (*PE* = .018)	.17 (*PE* = .021)	−.02 (*PE* = .022)
Motor Frequency				.10 (*PE* = .022)	−.03 (*PE* = .022)
Muscle Amplitude					−.13 (*PE* = .022)

* Rectilinearity was assumed upon the basis of inspection of the scattergrams. However, when curves were plotted there appeared to be some tendency toward curvelinearity. Etas were computed for the relationships which were most suggestive of curvelinearity, but only in the case of the relationship between occipital frequency and muscle amplitude was eta even barely higher than *r* (eta = .24, *r* = .17).

the brain. The negative relationships between brain amplitude and frequency (occiput, −.50; and motor, −.38) are in agreement with the results of Knott and Travis (**28**). The only other correlations which are even barely significant are the ones obtained between heart rate and brain amplitude (occipital area, .33; motor area, .33). This is of special interest since the relationship between heart frequency and brain frequency is practically zero. The probable errors are all below .022. Lindsley and Rubenstein's (**26**) data bearing upon the realtionship between alpha frequency and heart frequency indicate practically no correlation.

In order to understand why the rest of these relationships should be so low, the curves in Fig. 2 present the average values of brain amplitude, muscle amplitude and brain frequency plotted against heart rate. From this figure it would appear that there is a relationship between heart frequency and brain amplitude and a lack of any correlation between heart rate and either occipital or motor area frequency. This seems to be a case in point to support Gibbs' (**15**) hypothesis that the cortex acts as a number of chemical oscillators, since in a chemical oscillator an increase in amplitude without a decrease in frequency must be produced by an increase in the amount of material involved in the reaction. If the cortex

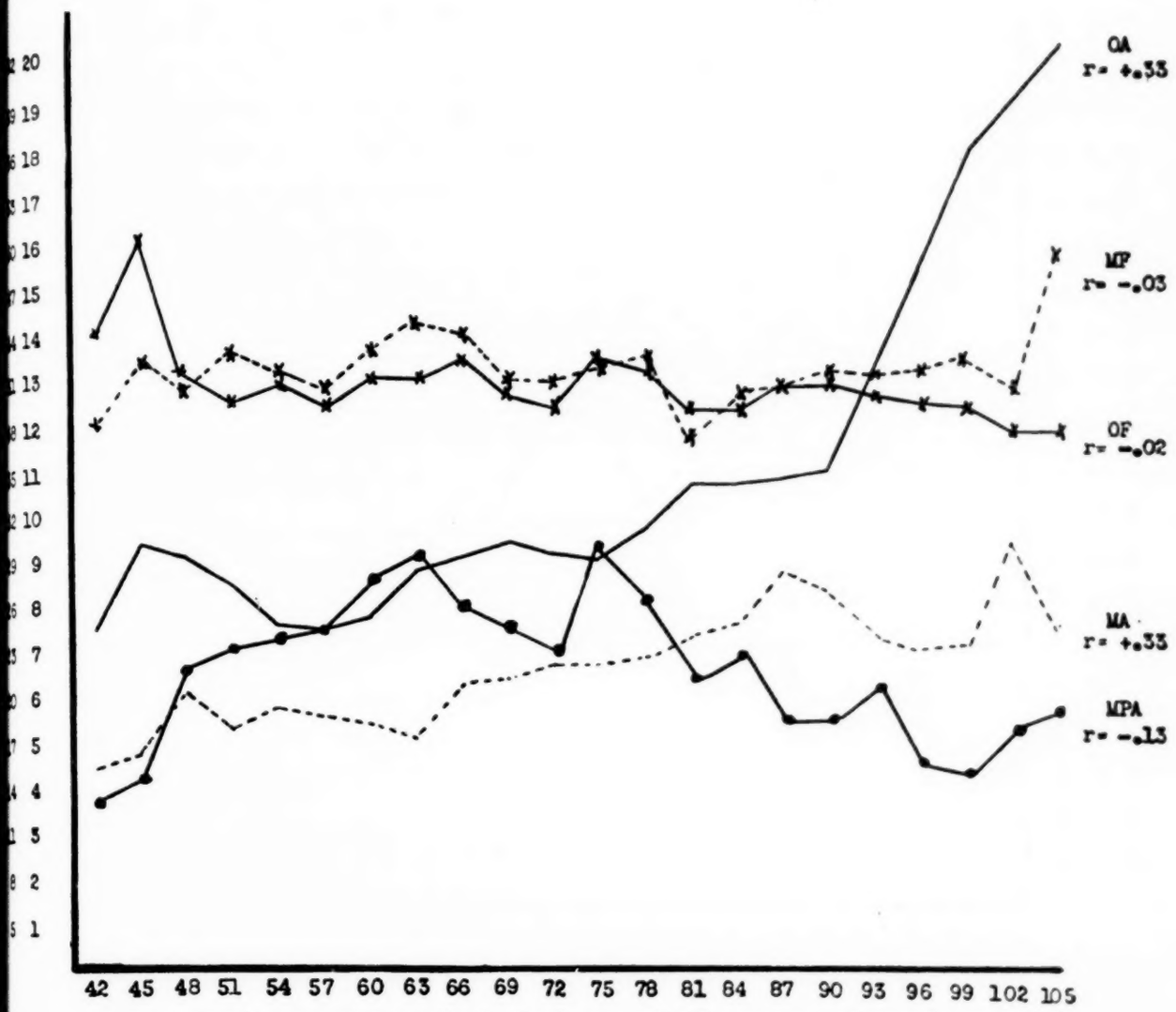

FIG. 2. Brain potential amplitude, brain potential frequency and muscle potential amplitude (on the ordinate) plotted against heart rate (on the abscissa).

acts as a chemical oscillator, then the material involved in the reaction must be maintained by the constituents of the blood. Although heart rate is not directly proportional to the amount of blood flowing to the cortex (**18**), it seems evident that the amplitude of the brain potentials may be in part dependent upon the blood flow.

Figure 3 shows curves of brain potential amplitude, brain potential frequency and heart rate plotted against muscle amplitude. Considering only those portions of the brain frequency curves below a muscle action potential level of 13 microvolts, no consistent relationship is apparent. However, there is a positive but low relationship between brain frequency and

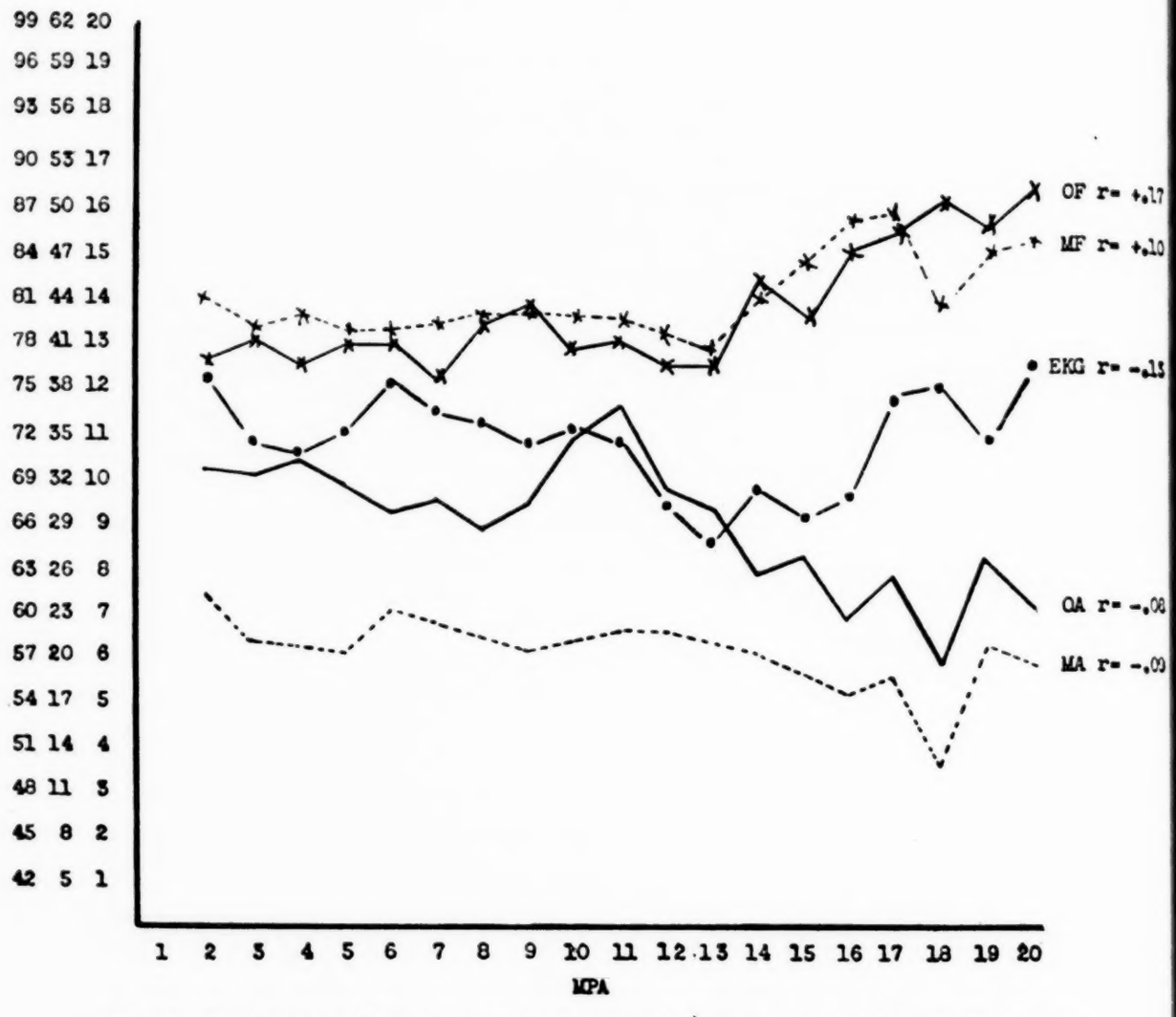

FIG. 3. Brain potential amplitude, brain potential frequency and heart rate (on the ordinate) plotted against muscle potential amplitude (on the abscissa).

muscle action potential amplitude when the portion of the curve above a muscle action potential of 13 microvolts is considered. The correlations involving only these latter seconds of muscle action potential are .34 (PE = .063) and .36 (PE = .062) for occipital and precentral areas respectively.

In those seconds characterized by a muscle amplitude of 11, 12, or 13 microvolts, or higher, the brain amplitude curves tend to be lower ($r = -.12$, PE = .073 and $r = -.26$, PE = .067, for occipital and precentral areas respectively), whereas, below that point there is no relationship between brain amplitude and muscle amplitude. At the same point of departure (13 microvolts) we find that the heart rate rises

concomitantly with the rise in muscle amplitude (r = .27, PE = .074). R. C. Davis (9) considers a muscle potential level of less than 10 microvolts as necessary for a condition of relaxation. The only consistent relationships between the variables studied were found when this level was above 10 microvolts.

In order to ascertain whether the relationships indicated by the gross correlations were occasioned by concomitant second by second variations in the recorded measures or were due to, or obscured by, inter-individual variations, correlations were computed between all the measures for each individual subject.

TABLE 3

RANGES, AVERAGES AND AVERAGE PROBABLE ERRORS OF THE CORRELATIONS COMPUTED ON EACH OF THE 20 SUBJECTS (AVERAGE N = 45 SEC.)

Measures Compared	Range	Average r	Average PE
Occipital Amplitude and Motor Amplitude	−.11 to .83	.40	.08
Occipital Amplitude and Occipital Frequency	−.65 to −.17	−.42	.08
Occipital Amplitude and Muscle Amplitude	−.63 to .62	−.16	.10
Occipital Amplitude and Heart Rate	−.66 to .70	.13	.10
Motor Amplitude and Motor Frequency	−.65 to .72	−.32	.09
Motor Amplitude and Muscle Amplitude	−.77 to .94	.00	.10
Motor Amplitude and Heart Rate	−.79 to .51	.09	.10
Occipital Frequency and Motor Frequency	−.14 to .70	.30	.09
Occipital Frequency and Muscle Amplitude	−.46 to .73	.21	.09
Occipital Frequency and Heart Rate	−.40 to .36	.03	.10
Motor Frequency and Muscle Amplitude	−.27 to .60	.20	.09
Motor Frequency and Heart Rate	−.33 to .47	.11	.10
Muscle Amplitude and Heart Rate	−.52 to .84	.02	.10

Table 3 gives the averages for these correlations together with the average probable errors and the ranges of the correlations. It is evident from the ranges of these correlations, which vary from high negative to high positive, that there

are extensive individual differences. In general it is true that the sizes and the directions of these average correlations are consistent with the gross correlations. The only exceptions occur in the case of the correlations between brain potential amplitude and heart rate. The evidently significant positive relationship between brain potential amplitude and heart rate does not appear significant when the average correlations are considered. This would suggest, in this instance, that between individuals there was some relationship between heart rate and the amplitude of the brain rhythms which was not so pronounced when second by second variations in a given individual were considered. *However, in view of the lack of consistency between subjects, the lowness of the correlation coefficients and the size of the probable errors, it would appear that one must be cautious in interpreting the relationships between brain and muscle or brain and heart as highly significant, at least until the significance of individual differences is established.*

Figure 3 indicates that the relationships between the various measures may be higher when the general level of activity is higher. Since there are such extreme differences between individuals as to the magnitude and direction of the various relationships, the possibility arises that these differences may be related to individual differences in either peripheral or general bodily activity. Consequently, the subjects were divided into four groups upon the basis of heart rates and muscle action potential amplitudes and the average correlations for each of these groups computed. In Table 4, Q_1 refers to the five subjects having the lowest average heart rate or the lowest average level of muscular activity, and Q_4 refers to the five subjects having the highest average heart rate and the highest average level of muscular activity. Q_2 and Q_3 represent, of course, intermediate steps. In looking at the table one sees no consistent relationship between the size of the average correlation for any given group and the speed of their heart or the height of their muscle action potential levels.

The only relationships which appear even barely significant are those between frequency of brain rhythm and muscle potential amplitude. When the gross correlations were con-

TABLE 4

AVERAGE CORRELATIONS FOR GROUPS DIVIDED INTO QUARTILES UPON THE BASIS OF AVERAGE MUSCLE ACTION POTENTIAL LEVELS AND AVERAGE HEART RATES

Measures Compared	Muscle Amplitude				Heart Rate			
	Q_1	Q_2	Q_3	Q_4	Q_1	Q_2	Q_3	Q_4
Occipital Amplitude and Motor Amplitude	.40	.48	.45	.30	.35	.38	.52	.34
Occipital Amplitude and Occipital Frequency	−.32	−.51	−.50	−.35	−.50	−.45	−.43	−.31
Occipital Amplitude and Muscle Amplitude	.05	−.21	−.19	−.23	−.22	−.22	−.39	.17
Occipital Amplitude and Heart Rate	.17	.13	.23	.04	.07	.13	.07	.29
Motor Amplitude and Motor Frequency	−.21	−.28	−.38	−.38	−.12	−.44	−.44	−.24
Motor Amplitude and Muscle Amplitude	−.02	.08	−.02	.08	.18	−.28	−.13	.19
Motor Amplitude and Heart Rate	.12	.11	.25	−.06	.02	.20	−.02	.12
Occipital Frequency and Motor Frequency	.19	.34	.40	.34	.41	.26	.45	.08
Occipital Frequency and Muscle Amplitude	.26	.10	.26	.26	.26	.17	.26	.16
Occipital Frequency and Heart Rate	.05	.04	−.08	.07	.09	−.08	−.08	.08
Motor Frequency and Muscle Amplitude	.16	.25	.12	.22	.23	.16	.22	.18
Motor Frequency and Heart Rate	.17	.05	.12	.14	.20	.03	.10	.12
Muscle Amplitude and Heart Rate	−.10	.18	−.02	.03	.42	−.30	−.16	.13

sidered, coefficients of .17 and .10 were obtained between occipital and motor frequency and muscle amplitude. These figures were slightly higher (.21 and .20) when the average correlations were considered. It is interesting to note that 80 percent of the subjects showed some positive correlation between occipital frequency and muscle amplitude, and 75 percent showed a positive relationship between motor frequency and muscle amplitude.

TABLE 5

AVERAGE CORRELATIONS, AVERAGE MUSCLE ACTION POTENTIAL AMPLITUDES AND AVERAGE CORTICAL FREQUENCIES FOR SUBJECTS SEPARATED INTO GROUPS UPON THE BASIS OF THE DIRECTION OF RELATIONSHIP BETWEEN CORTICAL FREQUENCY AND MUSCLE AMPLITUDE

	Average *r*	Average Muscle Amplitude in Microvolts	Average Cortical Frequency in Waves per Sec.
Positive *r* between Occipital Frequency and Muscle Amplitude	.33	7.6	13.7
Negative *r* between Occipital Frequency and Muscle Amplitude	−.35	7.0	11.9
Positive *r* between Motor Frequency and Muscle Amplitude	.30	7.9	13.6
Negative *r* between Motor Frequency and Muscle Amplitude	−.12	7.2	13.6

Table 5 presents data comparing the groups in which there was a negative relationship with those in which there was a positive relationship. In this instance, as before, we find some indication of higher relationships when muscle amplitude and brain frequencies are high.

DISCUSSION

The purpose of the present study was two fold: to explore the relationships between an electrical sign of central activity, the electroencephalogram, and two other electrical signs of bodily activity, the electromyogram and the electrocardiogram; and to attempt an interpretation of the data in terms of current theories of psychological processes.

No consistent relationships were obtained between any of the measures of central and peripheral activity used in this experiment.

One might conclude that the activity of three separate, discrete functional systems was sampled and that these systems function independently of each other. However, it is evident from a detailed analysis that the highest levels of cortical activity, as indicated by the frequency of cortical potentials, were found in seconds containing the most muscular activity, as indicated by the amplitude of the muscle action potentials. Furthermore, when the subjects from whom the positive correlations between brain frequency and muscle amplitude were obtained are compared with the subjects from whom negative correlations were obtained, the first group is characterized by slightly higher average brain frequencies and muscle amplitudes. (The groups unfortunately were too small for statistical comparisons to be made.)

R. C. Davis and his co-workers (**5**, **6**, **7**, **8**, **9**, **10**) have an imposing array of evidence indicating that increased muscle action potential amplitude accompanies psychological work. Similarly, the various electroencephalographic data discussed by Knott (**24**) indicate that increased brain potential frequency may accompany psychological work. This leads to the hypothesis that during activity, at least, there should be some relationship or correspondence between these two electrical phenomena.

Therefore, before one concludes that the functioning of the cortex, the muscles and the heart, as measured electrically, are not related, the possibility of relationships must be investigated when subjects are psychologically active.

If the results of such an investigation are negative, the validity of the measures used will need consideration. It is possible, even though the existing evidence makes it seem improbable, that the electroencephalogram is of no use as a psychological 'litmus paper,' or that the electromyogram is not an adequate sign of peripheral activity. It is further possible that, as suggested before, all of these electrical phenomena are quite discrete.

The negative results in the present study would appear to be of significance in considering the concept of the postural substrate.

Skeletal muscular tension and the secretions of endocrine glands are said to be very important to this 'general organic background' which operates to sustain and determine the 'vigilance' of the central nervous system (**13**, **14**). Freeman (**13**) discusses the possible use of the electroencephalogram as an index of central nervous activity and the electromyogram as an index to the activity of skeletal muscles. The level of mental activity is hypothecated to be a function of bodily activity throughout the range from 'sleep' to 'collapse' (**14**).

Whether or not one can postulate exact concomitance between muscle action potential level and cortical frequency level on the basis of the concept of the postural substrate is entirely problematical. If the muscle action potential level in the resting state is an index of the *general* tonic substrate activating proprioceptive systems and so leading to cortical disturbances, such a postulation, as suggested above, should be verified. That it was not leads to a careful consideration of the postural substrate.

One might have predicted from the hypothesis that variations in muscle action potential level and cortical frequency level would correlate fairly well (at least above .50 or .60). The lack of correlation indicates that: (*a*) the postural substrate is not an adequately defined concept, or else it is not a useful concept; or, (*b*) the electromyogram and the electroencephalogram are not specific enough as indicators of their respective physiological processes; or, (*c*) the electromyogram and the electroencephalogram are too specific (or local) as indicators of their respective physiological processes.

Since 'possibility (*c*)' is a probability as well as a possibility, 'possibility (*a*)' also becomes a probability, for if the methods of testing the concept recommended in principle by its author (**13**, p. 328–331) do not support it, the concept has not exhibited predictive powers, and thus becomes inadequate, at least with current experimental techniques and current verbal techniques for the discussion of data secured by them.

The postural substrate, as a generality, seems reasonable and indeed likely. The concerted efforts of a number of laboratories may give it powers of prediction which will provide

an adequate test of its theoretical fruitfulness. It is suggested that such efforts be made.

Summary and Conclusions

1. The problem of the relationship between central and peripheral activity has been approached through the use of the electroencephalogram, the electromyogram and the electrocardiogram. Simultaneous recordings of these phenomena were made from 20 adult normal subjects.

2. No consistent relationships were obtained between these various signs of activity while the organism was in a waking, but resting, state.

3. It was concluded that during a resting state three rather separate and distinct functional systems, operating independently of each other, were recorded.

4. The suggestion was made that during a psychologically active state more consistent relationships would be obtained.

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NEUROPHYSIOLOGICAL AND PSYCHOLOGICAL CHANGES INDUCED BY CERTAIN DRUGS: I. RESPONSES TO ELECTRICAL STIMULATION [1]

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The use of drugs as a means of experimental approach to psychological and psychopathological problems affords direct access to certain physiological relationships, and for this reason such methods have been widely used (**76**). However, the nature of the observations made, and the interpretations of the results have varied according to the particular viewpoints and objectives of the experimenters. Kraepelin and Nissl, for example, carried out their work with the hope of producing artificial psychotic conditions which could be correlated with histological changes produced by the drug, on the assumption that there is an organic basis for psychotic conditions. Later workers in the field of psychopathology have utilized more recent psychiatric viewpoints in the study of drug phenomena. Such work is exemplified by that of Lindemann (**65**) and Lindemann and Malamud (**67**). A wide diversity of other attempts to gain insight into the nature of psychological phenomena, both normal and abnormal, through the use of pharmacological agents might be quoted. The purpose of the present work has been the study of neurophysiological measures in relation to the action of drugs affecting the nervous system and to the psychological changes involved.

[1] This is the first of two papers which together comprise the main content of a dissertation submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the Department of Psychology, in the Graduate College of the State University of Iowa, January, 1940.

[2] Appreciation is expressed to Dr. Jacques Gottlieb and Dr. William Malamud for their time and assistance in this study, which was made possible through the coöperation of the Psychopathic Hospital of the University of Iowa.

In this study, the influence of four drugs (adrenalin,[3] mecholyl,[4] cocaine,[5] and sodium amytal [6]) will be considered. The study is divided into two parts, according to the two types of neurophysiological observations made. In both parts the psychological changes which occurred after the administration of the drug concerned were recorded. These data consist of observations of and subjective reports given by the subject spontaneously or in response to questioning. In the first group of experiments, measurements of rheobase, chronaxie and effects of repeated stimuli upon intensity and duration, respectively, with reference to the chronaxie point, were made upon a peripheral nerve and its muscle. In the second group of experiments electrocortical potentials were recorded and changes subsequent to drug injections were noted.

The Effect of Adrenalin, Mecholyl, Cocaine and Sodium Amytal Upon Responses to Quantitative Electrical Stimulation

The introduction of the time factor in studies of tissue excitability is generally accredited to Lapicque (**50**), who formulated the concept of chronaxie. Hoorweg and Weiss (**83**) had previously studied the relationship between intensity and current duration when comparatively short durations were employed. Prior to these studies, the law of DuBois-Reymond, which emphasized only the intensity factor, was generally conceded to characterize adequately the nature of excitability as determined by electrical stimuli. Lucas (**68**) in 1907 emphasized the importance of the time factor, and Lapicque, in 1909 (**49**) proposed for it the term chronaxie, which he defined as the duration of current necessary to produce a threshold response when the intensity is twice the rheobase, the rheobase being that minimal intensity of current required to excite when the duration of the current is greater than the critical value below which the intensity becomes de-

[3] The adrenalin (epinephrine) used was the synthetic preparation of the chloride in 1 : 1000 dilution.

[4] Acetyl-B-methylcholine.

[5] Cocaine hydrochloride.

[6] Sodium iso-amyl ethyl barbiturate.

pendent upon the time of stimulation. In the last two decades a variety of data have been collected in which the time factor has been measured (**21**, **29**, **85**). Determinations of excitability have been carried out upon single nerve fiber preparations, nerve-muscle complexes, sense organs, the spinal cord and various areas of the brain, in relation to many factors influencing the functional state of the nervous system, and the concept of 'chronaxic switching' (**52**) has been proposed as a basis for the explanation of selective functioning of the central nervous system. Lapicque has differentiated subordination and constitutional chronaxies (**51**), the former value being that obtained when the tissue in question is functioning under the influence of the nervous centers, while the latter is that value ascribed to the tissue in its own right after removal of this influence.

Modified techniques have been devised to permit clinical studies upon man (**38**, **59**, **82**). While much work has been done with drugs in the study of nerve and muscle tissue, relatively little use has been made of available clinical procedures in relation to the effects of drugs upon man. Malamud, Lindemann and Jasper (**69**), studying the effects of alcohol, found changes in the motor chronaxie and in the flexor-extensor ratio under this drug. Lindemann (**64**), using adrenalin, sodium amytal, cocaine, mescaline and hasheesh, discusses similar changes with these drugs. The results, though suggestive, were difficult of interpretation, and the present study was undertaken with a view to determining whether or not modifications in the apparatus and technique used in such work would prove enlightening.

Colle and Delville (**18**) and others have suggested that excitability is not adequately characterized by the two parameters of intensity and time alone, and the difference between subordination and constitutional chronaxies indicates that frequency of stimulation should also be taken into consideration, especially in studies made upon the intact organism, since in normal functioning of the nervous system series of stimuli rather than isolated ones are the rule, rather than the exception. For these reasons a modification of the ap-

paratus, permitting the use of repetitive stimuli as well as single stimuli, was utilized, as in a previous study by Weisz, Malamud and Fowler (**84**).

A second modification, not used in any previous study, concerns the type of electrode used. Davis (**20**) has commented upon the relationship of the size of the stimulating electrode to the chronaxie value of muscle, and Lapicque (**53**) has criticized the work of Grundfest (**36**) and others upon the basis of differences in the method of application of the electric current. The type of active electrode conventionally used in clinical studies is that described by Bourguignon (**11**). This consists essentially of a handle to which is attached a chlorided disc of silver, covered with canton flannel and bound with gauze. In use, the electrode is dipped in physiological saline solution and then held in place by hand upon the subject's skin over the motor point of the nerve, which is first found by exploration. Such an arrangement for stimulation is open to several objections, as was determined by a preliminary study made with the object of eliminating as many uncontrolled factors as possible. The values obtained with this type of electrode were found to be influenced by slight movements of the contact surface on the skin, by alterations in the pressure of the electrode upon the surface of the skin, and by spreading and evaporation of the saline solution on the surface of the skin. Accordingly, an electrode (to be described shortly) was devised to eliminate these factors.

Apparatus and Procedure

The chronaximeter used in this study consisted of the condenser-discharge type of apparatus described by Bourguignon (**11**), with, however, a variable resistor of 20,000 ohms in the shunt-circuit for the subject instead of the constant resistor of 11,000 ohms employed in the Bourguignon circuit. By means of this modification, the resistance in the shunt-circuit for the subject could be adjusted so that the total resistance was always held at 10,600 ohms. This value was selected, since its substitution in the formula for the time of a condenser discharge, $T = .375\ RC$ (where T is in seconds, R in ohms, and C in microfarads), simplifies the formula to $t = 4\ C$ (where t is in milliseconds and C is in microfarads), and the chronaxie is obtained directly by multiplying by 4 the capacity value found.

A 280 volt B-eliminator, supplied by 110 volt alternating current, was used as a charging source for the condensers. The condensers were thermostable and accurately adjusted.

The unit used for repetitive stimulation consisted of a motor-driven revolving drum having projecting teeth which as they passed a pair of contacts served as a switching device, alternately closing the charging circuit to the condensers, then opening this and simultaneously closing the discharge circuit to the patient; the number of times that this charging and discharging process occurred per second equaled the number of teeth which passed the pair of contacts per second. These contacts were movable and could be set at any given position along the drum so as to encounter any desired number of teeth up to 30 per revolution of the drum. A doubling gear ratio arrangement allowed either one or two revolutions per second of the drum; thus frequencies up to 60 per second could be obtained.

An indifferent electrode, consisting of a 6 × 10 cm silver plate, chlorided, covered with canton flannel and soaked in physiological saline solution, was fastened to the subject's chest. The subject was placed in a reclining position, with the arm and fingers relaxed. With a small electrode of the Bourguignon type, 5 mm in diameter, as the active electrode, the skin surface of the forearm was explored, using stimuli of varying intensity, in order to locate the optimal motor point, which was then carefully marked. All determinations were made upon the radial nerve and the muscles supplied by it. An electrode, consisting of a small rubber nipple with a hole in the top, an inner coil of chlorided silver wire sealed through the side, and having a bottom diameter of 5 mm, was then attached to the dried surface of the skin over the marked motor point by means of collodion. After the collodion had dried the electrode was filled with physiological saline solution by introducing the needle of a syringe through the small hole in the top. Thus a non-polarizable electrode having liquid contact with the skin over a constant surface area and at a constant pressure was formed.

In previous work the customary procedure had been to depend upon sight for the determination of the threshold response, watching the surface of the skin for indication of contraction of a muscle or movement of a tendon, and attempting to duplicate the least perceptible response by variation of the intensity or time factor, thus obtaining the threshold for the variable in question. This method is, however, open to several objections. The results are dependent upon lighting conditions, with reference to the position of the subject's arm, and a slight shift in position may alter the visibility markedly. Moreover, the success of the method varies with individual differences in anatomical makeup. In some cases the movement is easily perceptible, the muscle or tendon being thrown into bold relief when the current is applied and becoming imperceptible at a rather distinct threshold value. In other cases the amount of subcutaneous fat and the structure and disposition of the subcutaneous structures make the movement difficult to perceive and the end-point a matter of some conjecture. Because of these difficulties the use of some other method was decided upon. The use of various mechanical devices seemed limited either because of lack of sensitivity or impracticability in application under the experimental conditions. It was found, however, that the sense of touch could be used to decided advantage over the visual method. Following this procedure, the observer placed his fingers on the skin surface at the point at which he found the response to be most easily detected, and the stimulus was then varied above and below the threshold in accordance with the usual method for determining the threshold. By this means the results obtained were much more consistent and the end-point markedly more distinct than was the case when the visual method was used. A variation of one or two volts often sufficed to abolish or re-establish the response. Furthermore, the great individual differences encountered in the previous procedure were eliminated to a considerable extent, because of the greater

sensitivity of the touch determinations. For these reasons determination of the threshold by the touch method was used throughout the present series of experiments.

After adjusting the resistor of the chronaximeter to compensate for individual variations in skin resistance in order to obtain a total resistance of 10,600 ohms, the determinations were begun. The rheobase was first determined, then the chronaxie. Next, with the duration of the stimulus kept constant at the chronaxie value, intensity values necessary to produce the threshold response at frequencies of 4, 8, 12, 18, 24, 30, 40, 50 and 60 stimuli per second were determined, the repeated stimuli being applied for one second intervals. Following this, the intensity value was kept constant at twice the rheobasic value, and durations of stimuli for threshold response at the frequencies mentioned were determined.

Two control experiments, using no drugs, were run on each subject on separate days. The first control experiment consisted of three series of determinations of rheobase, chronaxie, and intensity and time variations with repetitive stimulation, these determination series being separated by 30 minute intervals. Throughout the experimental period the subject was reclining, and had received instructions to relax and lie quietly.

The second control experiment was made following at least a day's interval after the first experiment. In this period a complete set of control determinations was made, followed by a hypodermic injection of saline solution. Two subsequent sets of determinations followed, one 15 minutes after the injection and one 45 minutes after the injection.

In the drug series of experiments the same procedure was followed as in the saline control experiments. A set of control readings was made, followed by injection of the drug. Immediate and later determinations, 15 and 45 minutes, respectively, after administration of the drug, were then recorded.

Observations of the subject's behavior, spontaneous remarks, and information in response to questioning were recorded. Blood pressure and pulse readings were taken just prior to each set of electrical measurements.

At the conclusion of the experiment, if the subject was to be used again with another drug, the motor point used was carefully marked with methyl violet to insure its use in subsequent determinations. In all of the experiments of this group, each subject was used six times, at dates two or more days apart, and at approximately the same time of day. The series for each subject consisted of a control determination with no injection, a control with saline injection, subcutaneous injection of 1 cc. adrenalin hydrochloride in 1 : 1000 dilution, subcutaneous injection of 10 mg. mecholyl, subcutaneous injection of 50 mg. cocaine hydrochloride, and intravenous injection of 3¾ gr. sodium amytal.

Subjects.—The subjects were eight patients of the University of Iowa Psychopathic Hospital and one University student. Two of the patients were diagnosed as hebephrenic schizophrenia, one as catatonic schizophrenia, one as simple schizophrenia, two as manic-depressive depressed, one as psychopathic personality, and one as psychoneurotic.

Results

Tables 1, 2, 3 and 4 present the individual data obtained during six separate experimental periods utilizing the nine subjects. These tables express the maximum change obtained for the measure in question after the injection of the drug,

the figures being expressed as positive or negative, according to whether the maximum change was an increase or decrease over the control measurement taken at the beginning of the experimental period. By maximum change is meant the greatest difference between this first control determination,

TABLE 1

MAXIMUM CHANGE IN UNITS OF RHEOBASE (VOLTS) AND CHRONAXIE (MILLISECONDS) WITH INJECTION OF DRUGS *

Type of Case	Control		Saline		Adrenalin		Mecholyl		Cocaine		Sodium Amytal	
	R.	C.	R.	C.	R.	C.	R.	C.	R.	C.	R.	C.
Schizophrenia (simple)	+2	0	+3	−6	+7	+10	0	+30	+10	+8	+3	−2
Schizophrenia (hebephrenic)	+3	−36	+1	+6	+3	−22	+4	−40	+7	−36	−12	+8
Schizophrenia (hebephrenic)	+14	−4	+6	+6	−7	−8	−2	+6	0	+28	0	+4
Schizophrenia (catatonic)	+5	−4	−18	+10	+8	+6	−10	+32	−6	−4	−7	+14
Manic-Depressive (depressed)	+13	−4	−23	+6	+21	−6	+18	−22	−20	−8	+10	+20
Manic-Depressive (depressed)	+30	−8	+27	−2	+12	+8	+17	+2	+13	−4	+28	−20
Psychopathic Personality	+5	−4	−6	−12	−9	−6	+14	+6	+12	+4	0	+10
Psychoneurotic	+6	116	+9	−40	+6	−16	+7	−72	−8	+86	−5	0
Normal	0	+2	−16	+2	−3	+12	−6	+4	−11	+4	−8	−2

* These data and those in the following tables were obtained during six separate experimental periods for each of nine subjects.

TABLE 2

MAXIMUM CHANGE IN RHEOBASE AND CHRONAXIE, EXPRESSED IN PERCENT, WITH INJECTION OF DRUGS

Type of Case	Control		Saline		Adrenalin		Mecholyl		Cocaine		Sodium Amytal	
	R.	C.	R.	C.	R.	C.	R.	C.	R.	C.	R.	C.
Schizophrenia (simple)	+4	0	+8	−21	+12	+45	0	+212	+14	+36	+7	−10
Schizophrenia (hebephrenic)	+10	−56	+34	+21	+12	−38	+11	−284 +189	+21	−53	−40	+17
Schizophrenia (hebephrenic)	+26	−13	+9	+30	−12	−27	−33	+27	0	+116	0	+15
Schizophrenia (catatonic)	+11	−13	−27	+36	+16	+23	−20	+50	−11	−11	−16	+50
Manic-Depressive (depressed)	+17	−15	−24	+50	+33	−21	+33	−42	−26	−40	+21	+125
Manic-Depressive (depressed)	+43	−36	+36	−6	+15	+40	+20	+5	+15	−13	+36	−48
Psychopathic Personality	+8	−13	−10	+75	−20	−27	+27	+33	+21	+17	0 −25	+50 +17
Psychoneurotic	+16	−73	+26	−59	+15	−25	+20	−64	−18	+140	−9	0
Normal	0	+13	−22	+11	−5	+75	−11	+29	−17	+29	−17	−14

TABLE 3

MAXIMUM CHANGE IN INTENSITY AND TIME WITH REPEATED STIMULATION WITH INJECTION OF DRUGS

Type of Case	Control		Saline		Adrenalin		Mecholyl		Cocaine		Sodium Amytal	
	I	*t*	*I*	*t*	*I*	*t*	*I*	*t*	*I*	*t*	*I*	*t*
Schizophrenia (simple)	+8	+2	+1	−2	+3	+4	+16	+20	−10	+4	−6	−2
Schizophrenia (hebephrenic)	0	−20	0	+4	0	−8	−9	−2	−3	+4	+6	+16
Schizophrenia (hebephrenic)	+9	+2	+12	+6	+5	−8	−6	+8	+10	+24	−4	+6
Schizophrenia (catatonic)	−13	−10	−10	+6	+4	+4	−7	+8	+7	+4	−4	−8
Manic-Depressive (depressed)	0	−4	−2	+4	+8	+6	+5	−12	−31	−6	0	+4
Manic-Depressive (depressed)	+12	+2	+27	+4	+19	+6	+12	+2	+8	−4	+12	−10
Psychopathic Personality	+18	−4	+20	+14	−10	−8	+2	+6	−16	−4	+4	−6
Psychoneurotic	−3	−72	+6	+6	−4	−10	−3	−24	−3	+46	+4	0
Normal	−1	−13	−8	−12	+7	+29	−3	−11	−5	−15	−4	0

TABLE 4

MAXIMUM CHANGES IN INTENSITY AND TIME WITH REPEATED STIMULATION, EXPRESSED IN PERCENT, WITH INJECTION OF DRUGS

Type of Case	Control		Saline		Adrenalin		Mecholyl		Cocaine		Sodium Amytal	
	I	*t*	*I*	*t*	*I*	*t*	*I*	*t*	*I*	*t*	*I*	*t*
Schizophrenia (simple)	+6	+11	0	−3	+3	−7	+17	+43	−10	+4	−7	−5
Schizophrenia (hebephrenic)	−4	−31	0	+10	0	+14	−11	−11	+2	+19	+17	+29
Schizophrenia (hebephrenic)	+4	+13	+7	+21	+3	−26	−6	+21	+9	+19	−2	+16
Schizophrenia (catatonic)	−22	−29	−6	+13	+2	+8	−5	−11	+9	+14	−3	−14
Manic-Depressive (depressed)	+2	−11	+2	+20	+8	+27	+2	−18	−19	−37	−1	+11
Manic-Depressive (depressed)	+9	+14	+8	+12	+9	+13	+5	+2	−5	−12	−3	−3
Psychopathic Personality	−3	−37	+16	+39	−11	−40	−3	+22	−10	−26	−8	−17
Psychoneurotic	−5	−32	+6	+17	−5	−13	−3	−19	−2	−15	+5	0
Normal	−1	−13	−8	−13	+7	+29	−3	−14	−5	−14	−4	0

prior to the injection of the drug, and either of the later determinations; that is, if the difference between the control reading and the reading immediately following injection of the drug was greater than the difference between the control reading and the reading at the later period, this difference was recorded; if not, the other difference was recorded. Thus any tendency to consistent change should appear in the table.

Table 2 shows the maximum change in volts and milliseconds of rheobase and chronaxie. Table 2 expresses these changes in percent of rheobase and chronaxie. Table 3 shows the maximum change in volts and milliseconds as a result of summation effects with repeated stimuli. Table 4 expresses the latter changes in percent of intensity and time.

If the controls are compared with the results for each drug, it can be seen that there is no tendency for any drug to produce a consistent change in any of the measures taken. There are fluctuations both in sign and in magnitude, as in the control values, but in light of the control values there are neither any marked changes in magnitude nor consistent deviations in sign which are obviously ascribable to the effect of the drug. Likewise, no conclusions can be drawn as to the possible influence of psychopathological states.

Two possible conclusions thus present themselves: (1) the psychological effects produced by the drugs used are not accompanied by any detectable peripheral manifestations of alteration in excitability, or (2) such manifestations may occur but are not detectable by the methods used.

Discussion

In order to emphasize the nature of the results obtained in this study, mention will be made of pertinent researches in which changes in rheobase and chronaxie have been studied in relation to the action of various drugs upon physiological preparations. M. Lapicque and Vahl (**58**) found that in the cerebrate or decerebrate frog large doses of caffeine reduced the motor chronaxie of the sciatic nerve to half the value of the sensory chronaxie, when the thalamus was intact. They report that the effect of caffeine on the motor chronaxie is more distinct when the cord is free from the thalamic influence. M. Lapicque and Nattan-Larrier (**57**), using 1 mgm. doses of adrenalin, found a reduction of the chronaxie of the gastrocnemius muscle of the frog to one third its original value within thirty minutes. Adrenalin is also reported to diminish an increased muscular chronaxie due to fatigue. M. Lapicque has stated (**56**) that strychnine increases the excitability of

the motor nerve without affecting that of the corresponding muscle, and that a dose of this drug fifteen times as great is needed to produce the same effect on peripheral nerve when the higher centers are destroyed. Chloroform and ether may completely alter the chronaxie and rheobase, according to Buchanan and Garven (**16**), and L. Lapicque and Legendre (**55**) have contended that changes in excitability of myelinated nerve produced by chloroform, ether, cocaine and novocaine are paralleled by the morphological changes in the nerve, the chronaxie diminishing and the rheobase increasing with progressive swelling of the myelin sheath. The action of scopolamine, according to Rudeanu and Bonvallet (**73**), is to equalize the chronaxies of antagonistic muscles. Other work in addition to these researches might be quoted, which indicate that similar results might be inferred to be observable in studies upon man.

It is evident, however, that no such results have been obtained in the present experiments. Several possible differences in experimental technique at once suggest themselves. One is that many of the drug effects which have been reported have been obtained with pharmacological agents applied directly to the nerve or muscle in question, a procedure which would give a much greater concentration for local action of the drug, but which provides no information as to the central changes which are the primary interest of the present study. The type of stimulation employed in the clinical procedure is, because of its nature, more complex. Possible sensory stimulation and proprioceptive impulses due to the muscular response may complicate the picture. Stimulation through the skin is necessarily more diffuse and indefinite than that obtained by direct application of electrodes to a nerve trunk or muscle, even when electrodes of the type described in this study are used. Another serious problem is that introduced by the multiplicity of nerve fibers in the nerve trunk. Since, in a spinal nerve supplying striated muscle, a wide range of fiber diameters and corresponding variations in excitability of the individual nerve fibers may be found (**24**, **54**), the meaning of a difference in threshold for the nerve trunk is not clear.

Moreover, the relation of trunk fibers to motor units of the muscle, and the alternating behavior of motor units in muscular response only add further to the confusion when any attempt is made to reach a physiological interpretation of measurements made through the skin upon intact human nerve or muscle. Even if it were granted that by the methods used it is possible to measure accurately the chronaxie of a peripheral nerve and its muscle without reference to the above mentioned factors, there is still contention as to the theoretical significance of chronaxie. These controversial points have been well summed up by Davis and Forbes in their review (**21**). The interpretation of subordination and constitutional chronaxies is intimately tied up with these controversial points. Even the supposed influence of the nervous centers in determining subordination chronaxie values has been contested, Lambert, Skinner and Forbes (**47**) having found in one series of experiments that changes in rheobase and chronaxie found after section of a peripheral nerve, and supposedly due to release of the peripheral nerve from central control, are correlated only with proximity of the section in the nerve to the electrodes. Davis and Forbes have cited such evidence bearing upon subordination, pointing out that subordination now appears to be due to an alteration in the intensity factor rather than in the time factor of excitability, and that if subordination is, as it appears to be, a polarization effect which alters the rheobase of the nerve but leaves the time factor unchanged, the role originally assumed for chronaxie in the coördination of the nervous system can no longer be upheld. Further, the concepts of isochronism and the dependent theory of chronaxic switching, which were advanced to explain activity and coördination in the central nervous system, have been shown to be unwarranted as strictly applicable laws, both by experimental evidence and by theoretical analysis. It is also pointed out that mathematical formulations of excitability either obtained empirically or derived theoretically have failed to yield any single index of tissue excitability which may serve as an adequate representation, and that chronaxie must therefore rest upon its merits as an approximate empirical index.

Inasmuch as measurements of rheobase, chronaxie, and effects of repeated stimulation as described herein have failed to reveal any significant facts about the actions of drugs, it is suggested that a different criterion of excitability, possibly the determination of the strength-duration curve, might prove more enlightening in further work. That the failure of the results reported here to indicate any consistent changes ascribable to the effects of drugs might not be due entirely to difficulties in making clinical measurements as compared to measurements made upon physiological preparations, is suggested by the work of Knoefel (**45**) who investigated the effects of cocaine, chloral hydrate and urethane upon chronaxie and upon entire strength-duration curves, using frog's nerve and muscle. Knoefel found that the curves shift, that the chronaxie does not vary directly with the excitability as determined in this manner, and that these effects are independent of the nature of the stimulating electrodes, are not due to the 'alpha' effect (a slow excitability found in muscle when fluid electrodes are used), and cannot be attributed to pseudochronaxies; the further statement is made that it is questionable whether any single point can adequately represent the entire curve.

Whether or not utilization of the entire strength-duration curve as a measure of excitability would have any theoretical significance in further clinical studies is not pertinent here; the fact that chronaxie measurements alone may not be valid indexes of shifts in the curve is important. In the light of such evidence it would appear that inconsistency of chronaxie changes obtained under the effects of drugs does not necessarily imply inconsistency of changes in excitability. However, in view of the many factors involved, it would seem wise at the present time to forego any attempts at theoretical interpretation of results obtained in clinical studies, and to base such measurements upon the possibility of finding empirical data which might prove useful in differentiation.

(The second and last paper of this study, including the bibliography for both sections, will appear in a succeeding issue of this journal.)

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THE NEUROPHYSIOLOGY OF HEARING: I. THE MAGNITUDE OF THRESHOLD-STIMULI DURING RECOVERY FROM STIMULATION-DEAFNESS

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The work of Békésy and others indicates that adaptation is a lawful characteristic of human hearing (**2**, **16**, **19**), *i.e.*, the threshold-stimulus is raised for a period of time immediately following the termination of an intense tone. This indication is suggestive. It suggests a need for added controls as regards existing conditions in auditory experiments. There is suggested, for example, the need for a careful control of the factor of time in an exposure ($= I \times t$) to the auditory stimulus, and for a more complete specification concerning the condition of the test-organism. The indication also suggests the possibility that the magnitude of auditory threshold-stimuli may be governed by rules similar to those which operate in vision (**17**), kinesthesis (**10**, **11**), taste (**4**), and smell (**22**) during the course of recovery from the effects of previous stimulation.

These indications, of course, are not conclusive. Direct experimental results are needed to ascertain their actual status. Such results may be obtained simply and conveniently by submitting the auditory mechanism to the effects of strong, intermediate and weak exposures so as to produce in varying degrees what has been called 'fatigue' or 'stimulation-deafness' (**18**).

Certain of these indications, on the other hand, are actually required by theory. A theory which requires a specific alteration in the threshold-stimulus subsequent to an exposure is the theory of neural availability (**5**). According to this theory, the nerve-fibers and cells constituting the auditory nervous mechanism normally require a constant amount of activation in order to produce, remotely, a threshold amount of

excitation in the central nervous system. During stimulation, however, conditions are altered. The refractory periods of the activated nerve elements are presumably increased (3). Thus, a greater amount of stimulation at the receptors is needed to produce in the central nervous system the number of impulses per unit of time necessary for the perception of the tone. After stimulation, on the other hand, the refractory periods presumably decrease and gradually return to normal. Hence, immediately following the termination of a sufficiently intense tone, the amount of stimulation at the ear needed for tonal perception becomes smaller and smaller as a function of time and finally approximates the original pre-exposure value. On the basis of this neurophysiological conception, the intensity of the threshold-stimulus is expected to be greater immediately following exposure than immediately before it, and to decline gradually as a function of time until it reaches its nominal preëxposure value.

The present paper examines the validity of the predictions thus required by theory for experiment. Additional neurophysiological implications are also considered.

Apparatus, Method and General Procedure.—The output of a beat-frequency oscillator (GR Type 613-A) was amplified, filtered, led to a continuously variable attenuator, and thence to a pair of moving-coil receivers. The acoustic output of each receiver was measured by means of a sound-level meter calibrated against a condenser-microphone. The frequency of the tone used throughout the experiment was 800 c. p. s. Its acoustic purity was checked with a cathode-ray oscillograph and a wave-analyser (GR Type 636). The form was sinusoidal and the second harmonic *ca.* 1 percent of the fundamental at the highest intensity employed. The receivers were encased in sponge-rubber cushions which fitted snugly to the ears of the subject. All observations were made in an electrically shielded sound-room.

Threshold-stimuli were measured both before and after each exposure. Preëxposure threshold-stimuli were measured at the close of a five minute period during which the subject adapted to the 'silence' of the sound-room. The subject was then exposed to the tone (= 800 c. p. s.) for five minutes. At the end of this exposure-interval, the pressure-variation at the ear-drums due to the exposure-stimulus was immediately reduced to 'zero'. The magnitude of the threshold-stimulus for an 800 c. p. s. tone was then measured by the method of limits as a function of post-exposure time. Starting with an inaudible tone, the observer continuously increased the intensity at a constant rate until the tone was just heard. He repeated this procedure at specified times throughout the recovery-period.

Three exposure-intensities were used. The intensity-level of the loudest tone was 102 db; that of the intermediate sound, 82 db; and that of the weakest tone, 42 db above the adopted reference-level of 0.204 millibar. This value possesses the same

order of magnitude as the auditory threshold-stimulus usually obtained for an 800 c. p. s. tone. The exposure-time in every case was five minutes.

Results.—A number of complete curves have been obtained under these conditions for each of the subjects (the writers). The results for typical functions secured from two of these observers are presented in Table I and Fig. 1.

TABLE I

THRESHOLD-STIMULI IN LOG BARS FOR AN 800 C. P. S. TONE AS A FUNCTION OF POST-EXPOSURE TIME FOR THREE DIFFERENT EXPOSURE-INTENSITIES

The exposure-intensities were 42, 82 and 102 db; exposure-time (= 5 min.) and frequency (= 800 c. p. s.) were parameters.

t, secs.	A.H.H.			t, secs.	R.C.S.		
	42 db	82 db	102 db		42 db	82 db	102 db
12	$\bar{4}.80$			6	$\bar{3}.30$		
14		$\bar{3}.44$		10		$\bar{3}.62$	$\bar{2}.01$
24	$\bar{4}.68$			20	$\bar{3}.08$		
30		$\bar{3}.02$		24		$\bar{3}.48$	$\bar{3}.91$
34			$\bar{3}.56$	29	$\bar{3}.08$		
36		$\bar{4}.94$		32		$\bar{3}.30$	
38	$\bar{4}.62$			35	$\bar{3}.00$		
45		$\bar{4}.84$		40			$\bar{3}.77$
60			$\bar{3}.33$	50			$\bar{3}.60$
64		$\bar{4}.74$		55	$\bar{4}.90$	$\bar{3}.20$	
70	$\bar{4}.57$		$\bar{3}.20$	75			$\bar{3}.37$
85			$\bar{3}.08$	80	$\bar{4}.84$	$\bar{3}.08$	
90	$\bar{4}.54$	$\bar{4}.65$		100			$\bar{3}.24$
110	$\bar{4}.52$		$\bar{4}.96$	105	$\bar{4}.82$		
125		$\bar{4}.60$		110		$\bar{3}.00$	
130	$\bar{4}.53$			120	$\bar{4}.85$		
145			$\bar{4}.83$	140	$\bar{4}.78$		$\bar{3}.15$
160		$\bar{4}.60$		145		$\bar{4}.92$	
190			$\bar{4}.72$	170			$\bar{3}.08$
200		$\bar{4}.58$		175		$\bar{4}.90$	
225			$\bar{4}.68$	200			$\bar{3}.02$
230		$\bar{4}.58$		215		$\bar{4}.86$	
250		$\bar{4}.58$		230			$\bar{3}.05$
260			$\bar{4}.70$	270			$\bar{3}.00$
280		$\bar{4}.56$	$\bar{4}.66$	310			$\bar{4}.98$
300			$\bar{4}.64$	350			$\bar{4}.98$

The results presented in Table I demonstrate that the threshold-stimulus for hearing at 800 c. p. s. is a decreasing function of the time subsequent to the exposure. As the post-exposure time increases, the intensity of the threshold-stimulus decreases, continuously approaching the threshold-stimulus value obtained immediately before the exposure.

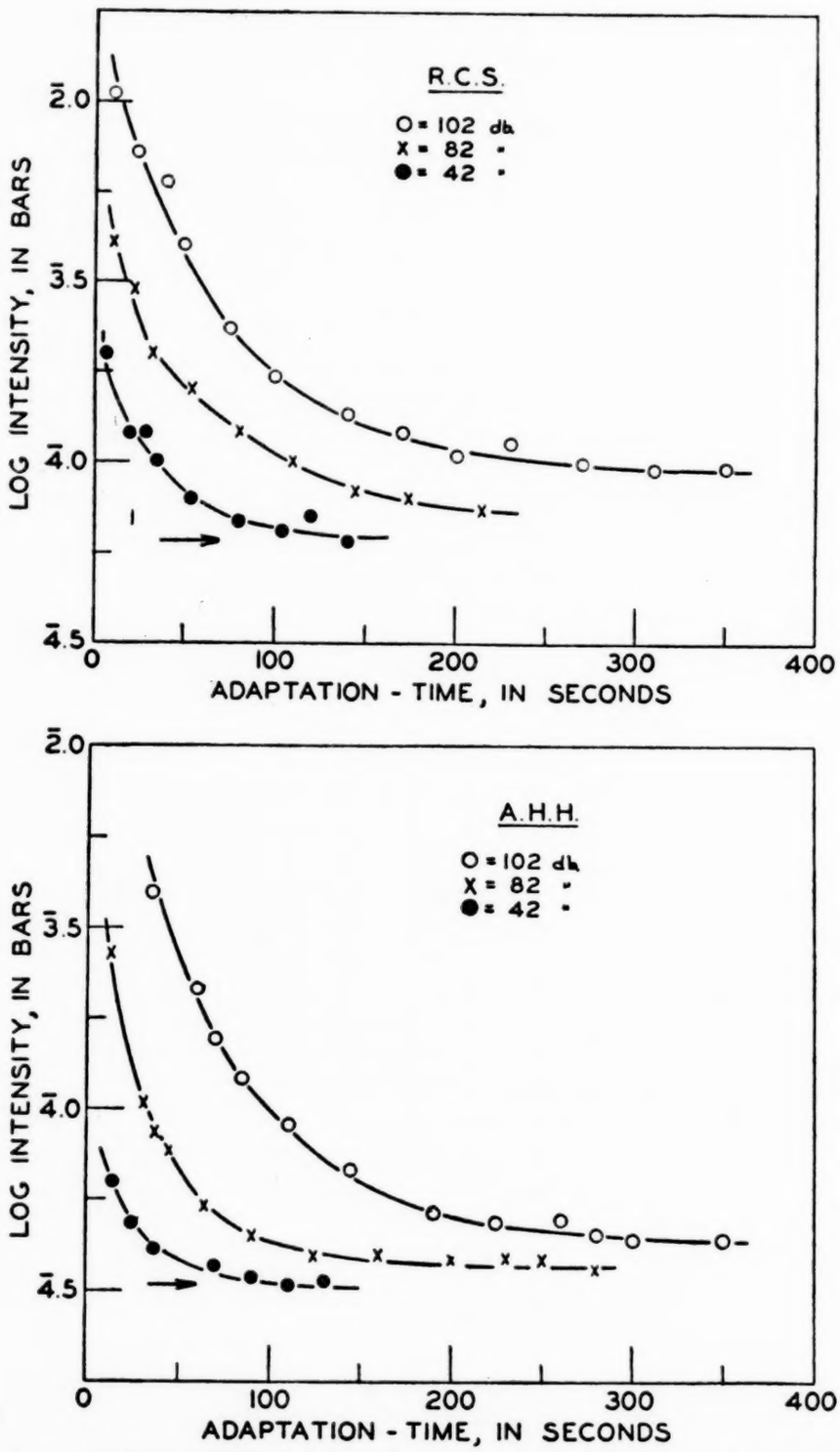

FIG. 1. Auditory threshold-intensity as a function of recovery-time following a five minute exposure to the indicated intensities (frequency = 800 c. p. s.) for two observers. The threshold-stimulus is a decreasing function of recovery-time. At any fixed time (= t, in secs.), moreover, the magnitude of the threshold-stimulus is an increasing function of the intensity of the exposure. The total recovery-time (= t) also varies directly with the exposure (= $I \times t$). For neurophysiological explanation, see text.

The general nature of this function is to be seen in Fig. 1 which contains three curves for each of two observers (A. H. H. and R. C. S.). The curves are typical. The ordinates are spaced logarithmically (log bars), the abscissæ in arithmetical units (secs.). The arrow drawn parallel to the axis of abscissas is in each case the mean value of the threshold-stimulus, secured at or near the close of the five minute preëxposure period.

These results show the inverse nature of the functions relating the magnitude of the threshold-stimulus to the post-exposure time for three stimulus-intensities. They also demonstrate that the magnitude of the threshold-stimulus at any moment during the recovery-interval is an increasing function of the exposure-intensity. Fifty seconds after the exposure ended, for instance, the threshold-stimulus is greatest for the 102 db tone, intermediate for the 82 db tone, and least for the 42 db tone. The total recovery-time accordingly varies directly with the exposure ($= I \times t$). These observations are valid for the results secured from each observer.

For completeness, it may be added that the rate of change in the threshold-stimulus with respect to post-exposure time (rate $= d\Delta I_0/dt$) for the conditions of this experiment is a single-valued, monotonic, decreasing function of the post-exposure time itself (*cf.*, **16**, **18**, **19**). This characterization is accurate for each of the functions shown in Fig. 1 and thus is independent of the particular exposure-values employed. The slopes of the functions are negative in all cases. For any one of the curves drawn in Fig. 1, the slope is numerically greatest at the outset, decreases rapidly at first, then iess rapidly, and finally tends to approach zero. For the more intense stimuli, the slopes do not quite reach zero; this, however, is due simply to the fact that the measurements were not taken for a sufficiently long period of time. No one of the functions drawn in Fig. 1 can be accurately fitted by a power function. When the data are plotted on a double-log grid (log I versus log t), each function exhibits a marked curvature. If the first measurement of each of the higher exposures is disregarded, then the curvature is always concave upward. These curves are to be

described analytically by a function which assumes the form of a general exponential equation.

Several of the plotted values depart considerably from the curve supposed to represent the trend of the measurements. One or two of these values are probably due to experimental error. Others, however, are probably not instrumental or accidental errors. They may be ascribed to lawful variations in the observer, *i.e.*, organic variations which may be cyclic in character.

These results naturally suggest the converse problem of determining the function that the threshold-stimulus is of recovery-time for exposure-intensity as parameter and exposure-time as variant. We plan to report on the nature of this function in the future.

Theory.—Theories of hearing usually accord special attention to cochlear functions. Less attention is paid to neurophysiological processes. The psychophysical facts described above, however, can be interpreted solely in terms of experimentally established neurophysiological findings.

Our interpretation follows the theoretical schema sketched at the outset of this paper. During any given exposure, the refractory periods of the involved nerve-fibers and cells may be assumed to increase by an amount which depends directly, if not proportionately, upon the stimulation-exposure ($= I \times t$). Such an assumption is consistent with two facts established by the works of Adrian (**1**) and Matthews (**15**): (*a*) during constant stimulation, the frequency of the impulses in a single nerve-fiber decreases as a function of time, and (*b*) the frequency at any given time is a direct function of the stimulating intensity. The assumption also harmonizes with the intensity-theory included in the volley-principle proposed by Wever and Bray (*cf.*, **21**).

Throughout the recovery-interval, the refractory periods of these anatomical elements may be assumed to decrease, continuously and gradually approximating their nominal value. This assumption is in harmony with the results presented by Field and Brücke (**3**), who investigated the recovery of excised nerve-fibers. Their results show that the refractory-periods

of nerves, completely separated from their peripheral endings, must recover in this manner as a function of post-exposure time.

Now, if the magnitude of the threshold-stimulus ($= \Delta I_0$) is assumed to depend upon the eventuation in the central nervous system of a constant number of impulses per unit of time, then the results of the present experiment can be sufficiently accounted for solely in terms of the neurophysiological activities just enumerated. The argument may be summarized as follows.

Each exposure increases the refractory periods of the involved nerves. The excitation per unit time available to the stimulus is thereby reduced, and an increase in the threshold-stimulus intensity is accordingly required to eventuate in unit time the number of impulses necessary for tonal perception. At any given instant during the interval of recovery, moreover, the threshold-stimulus is greater for the stronger exposures. It is greater because the refractory periods of the involved nerve-fibers are longer at that moment, wherefore fewer impulses per unit time are available to a given amount of the stimulus. Finally, the total recovery-period is longest for the strongest exposures because the refractory periods of nerves thus exposed recover most slowly (**1**, **3**, **15**).

We believe that this account provides a sufficient explanation of our findings. The explanation, however, is by no means complete. A complete explanation as to why the threshold-stimulus varies as it does during recovery would include factors which are not neural. The sensory cells in the ear, for instance, may operate according to the same laws as nerve for strong stimulation and recovery. Residual effects may also take place at the junctions or in the immediate environment of the sensory cells and nerves. These possibilities must be evaluated and ultimately written into the account which provides a complete interpretation. For the present, however, we would emphasize the fact that one can provide at least a sufficient if not a complete basis for expecting the results obtained in our experiment solely on experimentally established neurophysiological grounds. The

obvious advantage of such a theoretical basis for the interpretation of sensory data lies not only in its factual nature but also in its generality. As a basis, it applies to data for difference thresholds as well as for absolute thresholds in all departments of sense, *i.e.*, vision (**5, 7, 14, 17**), kinesthesis (**6, 8, 9, 10, 11**), taste (**4**), smell (**12, 22**).

Summary.—Following exposure to tones of different loudness, threshold-stimuli were measured as a function of recovery-time. The exposure-intensities were 42, 82 and 102 db above a reference-level of 0.204 millibar. Exposure-time (= 5 min.) and frequency (= 800 c. p. s.) were parameters. All measurements were secured by way of the method of limits (continuous increase at a constant rate).

Three principal facts were established by the measurements: (1) the threshold-stimulus as a function of post-exposure time was found to decrease continuously until it approximated its nominal preëxposure value; (2) at any instant during the interval of recovery, the magnitude of the threshold-stimulus varied directly with the exposure-intensity; and (3) the duration of the total recovery-period varied directly with the exposure-intensity.

These facts were explained in terms of the principle of neural availability.

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THE INFLUENCE OF MUSCULAR TENSION ON THE EYELID REFLEX *

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Experimentally induced muscular tension has been found to influence the level of performance in mental work (**2**) (**14**). With successive increments in the amount of tension induced by having the subject grip a Smedley hand-dynamometer, performance is facilitated until it reaches a maximum with an optimal amount of tension. Tensions beyond this point result in decrements, until with high degrees of tension performance finally falls below its normal level. Taking the dynamometer reading at the end of 30 sec. of maximum effort as a measure of the subject's strength, it was found that the optimal tension for memorization of consonant syllables is ¼ of this value (**2**). When tension is increased to ¾ of the basic value, performance falls below normal. On the other hand, the amplitude of the knee-jerk, measured in terms of quadriceps-thickening, was found to bear an approximately linear relationship to dynamometer tension between 0 and ¾ of the basic value (**1**). No decrement in the amplitude of response appeared with tensions within this range.

It has been suggested that among the various factors modifying the relationship between a performance and experimentally induced tension the complexity of an activity is important in determining how that activity will be affected by such tension. Freeman (**8**) has presented data which tend to show that the greater the complexity of the performance, the earlier in the series of increments in tension will inhibitory effects appear. If this is true, we should expect that where facilitation of performance occurs it should also appear earlier in the tension series with complex performances than it does in the case of simpler forms of behavior.

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The purpose of the present investigation is to determine the effect of dynamometer tension on a relatively simple form of action, the eyeblink reflex to a puff of air on the cornea.

Apparatus

The eyelid response was recorded photographically by the Dodge pendulum photochronograph (3). The stimulus consisted of a puff of air produced by releasing the pressure of 30 mm of mercury in a manometer tube. The puff was delivered simultaneously to the outer margin of the subject's left eye and to a strip of paper which cast a shadow on the lens of the photochronograph. Lid reactions were recorded from the left eye by means of an artificial paper eyelash which cast a second shadow on the lens. Two 10 cm squares of frosted glass, separated horizontally by a distance of 25 mm, and located directly in front of the subject at a distance of 65 cm from the eyes, constituted the field of fixation, which was viewed binocularly. Movements of the head during the recording of a response were minimized by having the subject bite on a tongue-depressor supported at each end in an adjustable clamp.

A Smedley hand-dynamometer, equipped with an adjustable electrical contact and fastened to a movable stand, was placed on a shelf under the table at which the subject was seated. The handle of the dynamometer was on a level with the subject's elbow. The electrical contact was connected with a relay which operated the source of illumination for the fixation field. When the dynamometer was gripped with a pressure equal to the setting of the contact ± 1 kg, the fixation field was illuminated with a brightness of 0.05 apparent foot-candles. The handles of the dynamometer were covered with ¼″ of sponge rubber.

Procedure

At the beginning of the experimental session, the subject was asked to grip the dynamometer as hard as possible and to maintain the pressure. The pressure maintained at the end of 30 sec was taken as an indication of the relative strength of the subjects. Two records were obtained of each subject's eyelid reflex under each of 7 degrees of tension. These were, in addition to the control condition of no dynamometer tension, tensions equal to ⅛, ¼, ⅜, ½, ⅝, and ¾ of the basic value as determined in the preliminary test of strength. Before recording each response, the experimenter gave the subject the command, 'squeeze.' Five sec after the fixation light went on, indicating that the correct amount of pressure was being maintained, the command 'blink' was given. Immediately after the eyelid had resumed its open position, the pendulum was released. The interval between the release of the pendulum and the air puff was 4 sec. There was an interval of 30 sec between the recording of a response and the signal for gripping the dynamometer for the next response under the same degree of tension. A rest period of 2 minutes was allowed between presentations of the various conditions. In the trials where no dynamometer tension was used, the experimenter turned on the fixation light as he gave a ready signal.

Experimental Design

The progressive increment (or decrement) in performance which accompanies practice in most psychological experi-

ments is frequently controlled by the counterbalanced order of presentation (A B C C′ B′ A′), in which the series of experimental conditions is repeated in reversed order. This procedure equates the means of the various conditions with regard to practice effects if the progressive effect of practice is linear, an assumption which is rarely justified. Another form of counterbalancing which is frequently used is that of rotating the series of conditions so that subject I begins the series with condition A, subject II with condition B, etc. This experimental design does not rest on the assumption of a linear practice gradient. It does, however, introduce an artificial increase in the variability of the obtained measurements. Thus, the estimate of the reliability of these measurements is too low. Furthermore, as this technique is frequently applied, the experiment is designed so that the various conditions are always in the same serial order except when they come at the beginning or the end of the series. When that is the case, the design fails to control possible interaction between the juxtaposed conditions. This latter source of possible error may be controlled by arranging the experimental conditions in all possible permutations, a task which becomes prohibitive except when a small number of conditions are used.

Experimenters in agriculture encounter a similar situation resulting from differences in the fertility of the soil in various portions of the experimental plot. These differences may be in the nature of a progressive gradient, or they may be randomly distributed. In the first case, their influence distorts the means of the various blocks within the plot. In the second case, the estimate of experimental error obtained from the total variance of the observations is magnified. In order to surmount these difficulties in field crop experimentation, R. A. Fisher (**5**) (**6**) has devised the Latin square design of experiment. This design randomizes the factors known to be capable of introducing constant errors into the sets of observations so as to permit an estimate of the variance of the observations from which has been subtracted the artificial variability introduced by the process of randomization. Thus, the variance produced by the experimental control is

not permitted to distort the estimate of experimental error. Furthermore, this design makes it possible to estimate the amount of variance contributed by each of the randomized factors.

The analysis of variance into its component parts so as to obtain a more accurate estimate of the reliability of the observations assumes that whatever factor has resulted in differences in the means of the different groups of observations has not produced significant differences in group variance (**10**, p. 99). In other words, differences in the soil in various blocks within the experimental plot, although making for distortion of the means, must have no effect on the variances of the yields from the blocks. In applying the Latin square design and the analysis of variance to psychological data, the practice effect may be considered as analogous to a gradient in fertility. Individual differences among subjects may be considered as analogous to unsystematic differences in the fertility of the blocks in the experimental plot. If the various portions of the total variance due to randomized factors are to be subtracted from the estimate of experimental error, it is necessary to make the assumption that practice effect has no significant effect on the variability of the group of subjects. This assumption can be justified only rarely. Consequently, an estimate of error from which the variance due to randomized factors has been subtracted would not be valid in most psychological experiments. This objection to the use of the analysis of variance may be met, however, by providing the subjects with sufficient preliminary practice for their performance to reach a plateau of relative imperviousness to the influence of further practice. Although it would no longer be necessary to control practice effect, it would be possible to use the analysis of variance and the Latin or Latin-Graeco square to control the effects of interaction and serial juxtaposition of conditions.

Another application of the analysis of variance is in the comparison of the relative significance of two factors in terms of the variance which may be attributed to each. After the variance of the total set of observations has been broken down

into portions associated with the different influences randomized in the experimental design, the relative importance of any two randomized factors may be determined by obtaining the ratio of the larger to the smaller of the variances associated with these factors. This ratio has been denoted as F by Snedecor (**13**, p. 173). Tables are available for the 5 percent and the 1 percent points of significance for the distribution of F. Although the use of the F-test is based on the assumption of homogeneity of variance, there is reason to believe that lack of homogeneity of the group variances does not invalidate its use (**10**, p. 139 ff.) (**13**, p. 178). Thus, it is possible to evaluate the relative importance of various factors in a psychological experiment, such as individual differences among subjects, experimental conditions, progressive practice effects, and interaction among the experimental conditions.

The design of the present experiment is in the form of a Latin square. The rows of the square correspond to individual subjects and the columns to serial order in the sequence of experimental conditions. The criteria to be met in designing such a square are that each condition occur once in each row and once in each column, and that, aside from these restrictions, the position of the experimental condition in the square be determined by chance. The design shown in Table 1 was constructed by drawing numbered beans from a box. Four complete experiments following this design were conducted. The 28 subjects were all undergraduates in a course in General Psychology. Two of the groups were made up of men and two of women. Each entry in the square is the mean of two responses recorded under the condition allotted to that cell of the square.

TABLE 1

ORDERS OF PRESENTATION OF EXPERIMENTAL CONDITIONS

Subject	Dynamometer Tension						
1	1/8	0	3/4	5/8	1/2	1/4	3/8
2	0	3/8	1/2	1/8	1/4	5/8	3/4
3	3/4	1/4	1/8	0	5/8	3/8	1/2
4	1/4	1/2	3/8	3/4	0	1/8	5/8
5	3/8	5/8	0	1/2	1/8	3/4	1/4
6	5/8	1/8	1/4	3/8	3/4	1/2	0
7	1/2	3/4	5/8	1/4	3/8	0	1/8

Results

Amplitude of Response.—Amplitude measurements of records of the eyelid reflex secured by means of the Dodge technique present certain difficulties. In the first place many subjects show such a range of response from the open to the closed position of the eyelid that it is difficult to keep the record on the paper. Secondly, after complete closure has occurred, the eyelid may move without producing movements of the artificial lash. Because of the first difficulty, it was not possible to use the records from all of the 28 subjects in obtaining measurements of amplitude. By selecting those subjects whose records did not run off the paper it was possible to make up a complete Latin square for subjects of each sex. For these two groups, the mean amplitudes of response, in terms of mm of deflection on the record, are shown in Table 2. All of the combined means from the tension conditions are lower than the combined mean for the control condition. The means under tension for the separate groups are in all cases but one lower than the mean for the control condition. No trend in amplitude with successive increments in tension is apparent.

TABLE 2

Mean Amplitudes of Eyelid Reflex Under Different Degrees of Tension (Measurements in mm of Deflection)

Group	Dynamometer Tension						
	0	¼	½	¾	1	1¼	1½
Men	45.1	46.4	44.1	44.5	43.9	42.7	41.8
Women	41.1	35.9	27.4	36.3	33.3	27.4	31.0
Combined	43.1	41.2	35.8	40.4	38.6	35.0	36.4

The results of the analysis of variance are shown in Table 3. Clearly there is no significant effect shown as the result of dynamometer tension. For both groups of subjects the variance attributable to experimental conditions is less than that associated with individual differences among subjects. It is also smaller than that associated with practice effect. The tension variance for the group of men is less than the residual

variance due to uncontrolled factors. For the group of women, the tension variance is greater than the residual. The *F*-value, however, is only 1.56, whereas the 5 percent point of significance when the larger variance is based on 6 degrees of freedom and the smaller on 30 is 2.42.

TABLE 3

ANALYSIS OF VARIANCE IN AMPLITUDE OF RESPONSE

Source of Variation	Degrees of Freedom	Sum of Squares		Mean Square	
		Men	Women	Men	Women
Total	48	5069.0	7252.3		
Subjects	6	2842.8	2416.3	473.8	402.7
Order	6	405.9	1057.1	67.6	176.1
Tension	6	35.2	897.6	5.9	149.6
Residual	30	1785.1	2881.3	59.5	96.0

Although the analysis of variance shows no significant change in amplitude with different degrees of tension, the possibility remains that tension, regardless of the amount, may affect the response. In order to test this, the average amplitude of response under all conditions of tension was determined for each subject. The difference between the mean of these values and the mean amplitude under no tension was 5.6 mm. The *t*-value was 1.93, which for 13 degrees of freedom would be exceeded by chance less than 10 percent of the time.

Probably tension exerts a slight attenuation of the amplitude of the eyelid reflex. This effect, however, is not statistically significant in terms of the *t*-test, nor is it important in comparison with other factors which contribute to the variability of response.

Latency.—It was possible to measure the latency of all of the records. The mean latencies in units of 0.01 sec. for the 4 groups of subjects and for the combined groups are shown in Table 4. Although the mean latencies under tension for the combined groups are all larger than the mean of the control condition, they show no consistent trend with increasing amounts of dynamometer tension.

TABLE 4

MEAN LATENCIES OF EYELID REFLEX UNDER DIFFERENT DEGREES OF TENSION (MEASUREMENTS IN 0.01 SEC.)

Group	Dynamometer Tension						
	0	¼	½	¾	1	1¼	1½
Men I	6.75	8.00	7.29	7.36	8.82	8.43	8.57
Men II	7.71	9.11	8.25	8.04	8.43	9.36	8.71
Women I	6.79	6.04	6.29	5.93	6.68	5.86	6.36
Women II	6.86	7.21	7.25	7.29	8.25	6.68	8.00
Combined	7.03	7.59	7.27	7.16	8.04	7.58	7.91

Table 5 shows the results of the analysis of the variances of the 4 groups. The variance associated with experimental condition is not significantly larger than that associated with individual differences among the subjects, or with practice effect. In the case of Group II of men the variance associated with condition is larger than that associated with serial position. The *F*-value is 3.96, while the 5 percent point of significance when both estimates of the variance are based on 6 degrees of freedom is 4.28. The tension conditions do not produce a significant variation in the latency of the response.

TABLE 5

ANALYSIS OF VARIANCE IN LATENCY OF RESPONSE

Source of Variation	Degrees of Freedom	Sum of Squares		Mean Square	
		Men I	Men II	Men I	Men II
Total	48	181.90	293.47		
Subjects	6	71.55	11.73	11.93	1.96
Order	6	24.16	3.18	4.03	0.53
Tension	6	24.50	12.58	4.08	2.10
Residual	30	61.79	265.98	2.06	8.87
		Women I	Women II	Women I	Women II
Total	48	143.40	168.57		
Subjects	6	68.55	74.75	11.42	12.46
Order	6	12.39	19.44	2.07	3.24
Tension	6	5.04	14.72	0.84	2.45
Residual	30	57.42	59.66	19.14	2.00

When the average latency under all tensions was compared with the latency under the control condition, the difference

was found to be 0.56 hundredths sec. The *t*-value is 1.93, which for 27 degrees of freedom would be exceeded by chance less than 10 percent of the time.

The slight increase of latency which is shown under the tension condition fails to meet even the 5 percent criterion of significance. Furthermore, the effect of dynamometer tension on latency of the eyelid reflex is relatively unimportant in comparison with the effect produced by other factors responsible for variation in the measurements.

Practice Effect.—Table 6 shows the mean amplitudes for serial positions in the experiment. There appears to be a slight decrease in amplitude with practice. This trend, however, is not statistically significant, as may be seen from the variances in Table 3.

TABLE 6

MEAN AMPLITUDES OF RESPONSE FOR SERIAL POSITIONS
(MEASUREMENTS IN MM OF DEFLECTION)

Group	Serial Position						
	1	2	3	4	5	6	7
Men	45.9	48.9	46.9	42.9	41.9	42.4	39.7
Women	41.1	35.9	27.4	36.3	33.3	27.4	31.0
Combined	43.5	42.4	37.2	39.6	37.6	34.9	35.4

The mean latencies for serial positions are shown in Table 7. Latency seems to decrease slightly as the experiment progresses. There is no evidence for a regular trend, and the variance associated with serial order is not significantly dif-

TABLE 7

MEAN LATENCIES OF RESPONSE FOR SERIAL POSITION
(MEASUREMENTS IN 0.01 SEC)

Group	Serial Position						
	1	2	3	4	5	6	7
Men I	8.18	8.18	7.43	9.29	6.86	7.57	7.71
Men II	9.18	8.54	8.57	8.57	7.96	8.46	8.32
Women I	7.32	6.21	5.43	6.32	6.29	5.93	6.43
Women II	8.54	7.89	7.21	6.50	7.00	7.11	7.29
Combined	8.30	7.70	7.16	7.67	7.03	7.27	7.44

ferent from that associated with experimental conditions (Table 5). Moreover, the residual variances in Table 5 show clearly that the variations in latency with practice are not significant.

Conclusions

Peak (**11**) has found that under conditions of relaxation the amplitude of the eyelid response is less and its latency is greater than when the subject is instructed to blink voluntarily to a light or when he is instructed to press a key in response to the sudden noise which elicits the blink. The subject was instructed to prepare for the voluntary finger depression by tensing his forearm so that he would be able to react more quickly. This suggests that muscular tension may increase the amplitude and decrease the latency of the eyelid reflex to a sudden noise. Peak (**12**) has also reported that the amplitude of the lid response tends to increase in direct proportion to the logarithm of stimulus intensity, and that this increase with increased stimulation is less under conditions of relaxation than under the relatively tense condition which accompanies voluntary set. The failure of the present investigation to corroborate her finding that the amplitude of response is greater when the subject tenses his forearm may be due to differences in the strength of stimulus used in the two experiments. Moreover, the effect of tension on the amplitude and latency of response may not be the same when the eyelid reflex is elicited by a puff of air to the cornea as when it is elicited by a sudden noise.

Freeman (**8**) has mentioned, without formally presenting the data, a small number of observations which suggest that tension induced in the lower limbs facilitates the eyelid reflex. Since the facilitation was not shown to be statistically significant, his results are not in conflict with those of the present study.

The fact that the eyelid reflex was not found to be significantly altered by dynamometer tension, while the knee-jerk is greatly facilitated by such tension (**1**), may be due to the relationship between the musculatures involved in these responses and the locus of the dynamometer tension. Freeman

(7) has presented evidence that optimal facilitation of a reaction is produced by tension in muscle groups most closely allied with the reacting member. The spread of tension resulting from dynamometer effort may be greater to the muscles involved in the knee-jerk than it is to those involved in the reflex blink.

The difference in susceptibility of the two responses to tension may, on the other hand, be due to differences in the neural pathways involved. The proprioceptive pathways excited by the sustained muscular tension result in a heightened level of cortical excitation. Numerous studies (4) indicate that the knee-jerk is extremely sensitive to the general level of activity in the nervous system. In contrast, the eyelid reflex in response to corneal stimulation is relatively specific with regard to the pathways involved. It is known that the barbituric acid anesthetics, which act specifically on the midbrain and hypothalamus, often abolish the corneal reflex before the patient becomes unconscious (9, p. 201). This suggests that the facilitative or inhibitory effect of experimentally induced muscular tension on a given activity is a function of the nervous pathways involved in that activity. In performances dependent upon cortical areas energized by the afferent tracts affected by the experimentally induced muscular tension, the effect of tension will be more apparent than in performances not dependent upon those areas.

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THE TIME OF ADMINISTRATION AND SOME EFFECTS OF 2 GRS. OF ALKALOID CAFFEINE

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On the basis of a preliminary study (1), the present investigator submitted a theory of boredom integrated about the hypnotic tendencies usually operating during a 'monotonous' task. In conformity with the theory, it was to be expected that certain antihypnotics should allay the development of a bored attitude to a repetitive task. Accordingly, the effects of benzedrine sulfate, ephedrine hydrochloride, an added incentive, and a lowered room temperature (2, 3, 4) on some indices of boredom during repetitive tasks were studied. It was reported that only a lowered room temperature (under certain specific conditions) was without effect on these indices.

Caffeine is well known for its antihypnotic qualities. Its effects on boredom would be of interest to the general problem outlined above. In a preliminary study [1] on 49 subjects, it was found that 2 grs. of alkaloid caffeine had an effect on the report of boredom and rate of addition which was somewhat similar to that of 10 mgs. of Benzedrine. As Hoch and Kraepelin (6) and Hollingworth (7) had previously reported, the rate of addition under caffeine was higher than under a control condition. A very striking fact observed in this study was the *lack* of any 'stimulating' effect of the caffeine on the initial adding performance. This fact was also observed in a previous experiment with Benzedrine (2) and with another type of task (3). In each instance the caffeine or Benzedrine was administered 30 minutes before the task was begun.

A purpose of the present study was to determine whether the *lack* of any initial caffeine effect on adding was due to the time of administration of the drug or whether it is obtained independently of the time of its administration. Specifically,

[1] Unpublished data.

the purpose of the present investigation was to compare the rates of addition and ratings on four 9-point subjective rating scales of bored-interested, peppy-fatigued, sleepy-wide-awake, and attentive-inattentive, of 29 subjects, adding for 8 successive fifteen-minute periods under the following four conditions:

a. 2 grs. of alkaloid caffeine, *one hour* before adding.
b. 2 grs. of alkaloid caffeine, *two hours* before adding.
c. 2 grs. of alkaloid caffeine, *three hours* before adding.
d. Placebo capsules before adding.

Subjects and Procedure

Twenty-nine college students (twenty-seven males and two females) volunteered as subjects for this experiment. The materials consisted of mimeographed sheets containing either 100 pairs of numbers to be added or subjective rating sheets. Six different adding sheets were used and duplicated with such rotation for all subjects that no single sheet had a position of advantage. The subjective rating sheet is illustrated in Fig. 1.

Name.....Code No.....Page No.....

Session.....Date.....

Please circle the numbers below which best describe your feelings or attitudes:

1.....2.....3.....4.....5.....6.....7.....8.....9....
Very Bored Bored Indifferent Interested Very Interested

1.....2.....3.....4.....5.....6.....7.....8.....9....
Very Peppy Peppy Indifferent Fatigued Very Fatigued

1.....2.....3.....4.....5.....6.....7.....8.....9....
Very Sleepy Sleepy Indifferent Wide Awake Very Wide Awake

1.....2.....3.....4.....5.....6.....7.....8.....9....
Very Attentive Attentive Indifferent Inattentive Very Inattentive

Fig. 1. The subjective rating sheet.

The procedure was basically as follows:

Every subject attended four experimental sessions at intervals of one week. At each session the subject was given 3 gelatin capsules at the rate of one per hour. The first capsule was given three hours before adding, the second was given two hours before adding, and the third was given one hour before adding. The gelatin capsules contained either 2 grs. of alkaloid caffeine or lactose. The subjects had no means of discriminating between them. Each subject participated in an experimental session at which the first, second, third, or none of the three capsules contained the caffeine. The order of the four conditions was so varied among the 29 subjects that for practical purposes, no one condition had a favored position.

The hours after the administration of each capsule were left free for the subject to

do as he or she pleased. Three hours after the first capsule was taken, the subjects filled out the first subjective rating sheet and then began to add under the instructions to "work as quickly and as accurately as you can." The subjects added for eight 15-minute periods at the end of each of which they were allowed 50 to 60 seconds in which to fill out a subjective rating sheet. After a work sheet or a self-rating sheet was completed, it was turned over face down and the subject did not subsequently refer to it.

For ten of the twenty-nine subjects, the first capsule was administered at 11.00 A.M. For the other nineteen, the first capsule was administered at 5.00 P.M. on experimental days.

Results

The results of this experiment are graphically presented in Fig. 2. The reliability of the differences between the caffeine and control mean adding rates of the sixth, seventh, and eighth periods may be determined by consulting the critical ratios of Table I.

TABLE I

Critical Ratios of the Mean Differences in Rate of Adding between Placebo and Caffeine Conditions at the Sixth, Seventh, and Eighth Periods

Period	Placebo and Caffeine One Hour Before	Placebo and Caffeine Two Hours Before	Placebo and Caffeine Three Hours Before
6th	3.00	2.13	1.90
7th	2.58	2.31	1.71
8th	2.20	2.30	1.41

In view of the consistency of the trend of the data, it is clear that the 2 grs. of caffeine favorably affect the rate of adding, particularly towards the latter part of a two-hour session of adding. The most significant differences occur with the caffeine administered one hour before starting to add. However, according to the data, the caffeine does not influence the *initial rate* of addition when the caffeine is administered one or three hours before adding. There is some doubt about the effect of caffeine on initial addition when it is administered two hours before. The critical ratio of the obtained difference between initial caffeine and placebo rates of addition where the drug was given two hours before is 0.58.

The reliability of the difference between the average subjective ratings for the caffeine and placebo conditions may be inferred from the critical ratios of Table II.

According to the data, the most striking and most significant subjective effects are obtained with caffeine administered one hour before adding. The magnitude of these effects is greatest approximately one hour after the work is begun, or two hours after the caffeine was given. Neverthe-

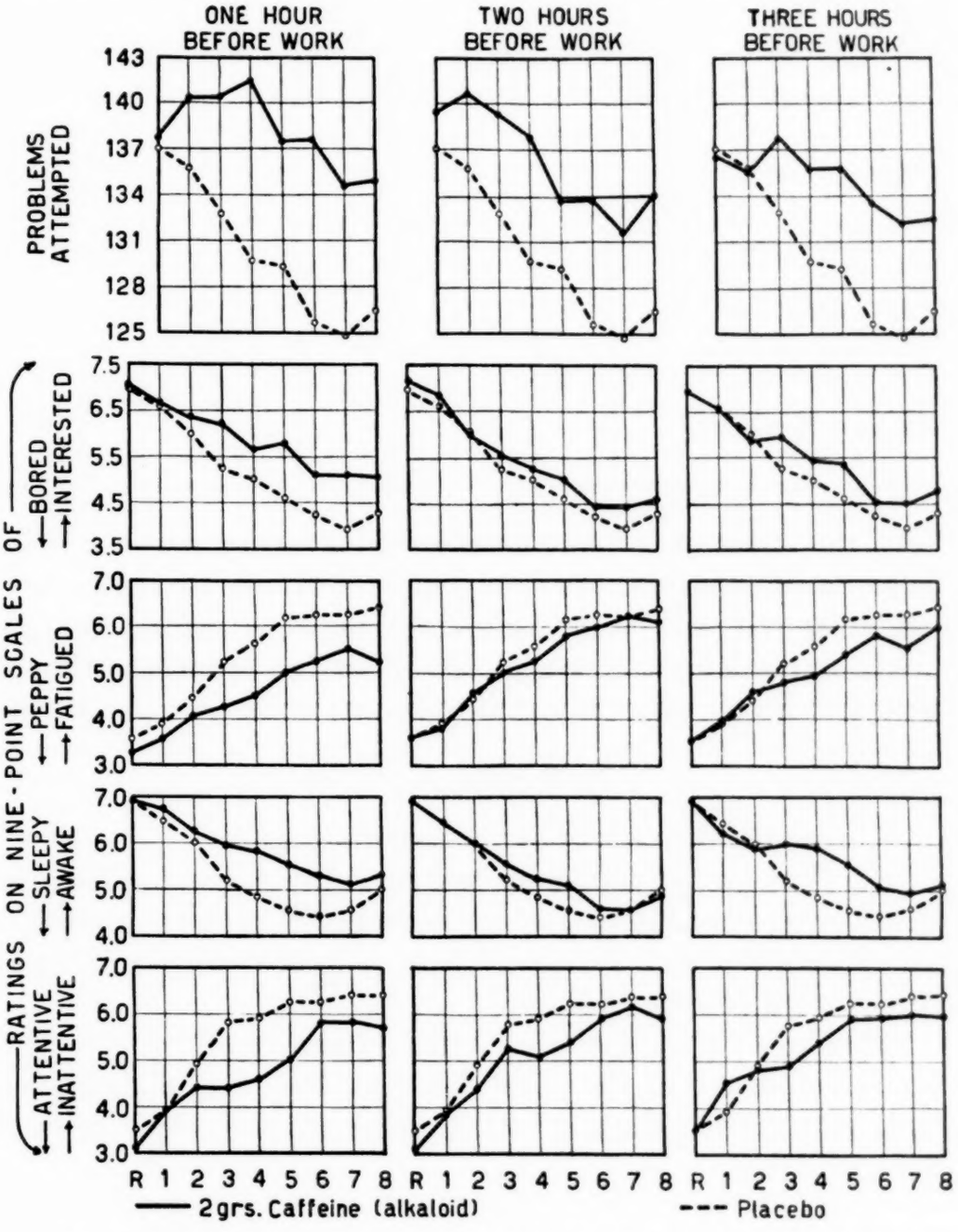

FIG. 2. The effect of the time of administration of 2 grs. of caffeine alkaloid on the subjective reports and rate of adding of 29 subjects for eight 15-minute periods. Arrows indicate the direction of the increase. R equals rest, and 1, 2, 3, etc., equal successive 15-minute periods of adding.

TABLE II

THE CRITICAL RATIOS OF SOME MEAN DIFFERENCES BETWEEN THE SUBJECTIVE RATINGS OF THE PLACEBO AND THREE CAFFEINE CONDITIONS

Subjective Rating Scale	Period	Placebo and Caffeine 1 Hr. Before	Placebo and Caffeine 2 Hrs. Before	Placebo and Caffeine 3 Hrs. Before
Bored-Interested	6	2.15	.50	0.74
	7	3.34	1.43	1.50
	8	1.43	1.11	1.04
Peppy-Fatigued	4	3.00	1.20	—
	5	3.40	1.05	—
	6	3.00	.90	1.62
	7	—	—	2.12
	8	—	—	1.00
Sleepy-Wide-Awake	3	—	1.00	2.67
	4	2.78	1.34	2.25
	5	2.73	1.82	2.78
	6	2.60	—	—
Attentive-Inattentive	3	3.01	1.00	3.10
	4	3.16	1.70	1.20
	5	3.16	2.37	1.05

less, the effect of caffeine on the *initial* ratings when caffeine is given *two* hours before is negligible. Similarly, the caffeine administered *three* hours before the onset of mental effort is without influence on the initial subjective reports, although some moderate effect is manifest in the latter part of the two-hour period.

SUMMARY

Under the conditions of the experiment:

1. Two grs. of alkaloid caffeine administered one hour before a two-hour period of addition allay the development of an unfavorable attitude to the task as indicated by subjective reports and rate of addition.

2. The effects of the caffeine administered *two* or *three* hours before are in the same direction but of smaller magnitude than those obtained with caffeine administered one hour before adding.

3. In all but one instance, the effect of two grs. of caffeine is not on *initial* rating or performance, regardless of the time of administration of the drug. The exception is the initial rate of adding with the caffeine administered two hours before.

Is this latter datum an artifact or are the other initial rates of addition due to chance?

To answer this question, a supplementary study on 36 other subjects was performed. This experiment was designed to permit a comparison of the rates of addition and subjective ratings of subjects adding for 15 minutes under the following three conditions:

a. 2 grs. of alkaloid caffeine two hours before adding.
b. 2 grs. of alkaloid caffeine three hours before adding.
c. Placebo before adding.

The materials, technique of control, and basic procedure were the same as that for the main experiment, with the exception that at each of the three sessions the subjects added for one 15-minute period instead of eight. The results of this experiment are provided in Table III.

TABLE III

A Comparison of the Rate of Adding and Certain Subjective Ratings Before and After Adding under (*a*) Placebo, (*b*) 2 grs. of Alkaloid Caffeine Administered Two Hours Before Adding, and (*c*) 2 grs. of Alkaloid Caffeine Administered Three Hours Before Adding. *N* Equals 36

Condition	Problems Attempted	Ratings Before Adding				Ratings After Adding			
		Bored-Interested	Peppy-Fatigued	Sleepy-Wide-Awake	Attentive-Inattentive	Bored-Interested	Peppy-Fatigued	Sleepy-Wide-Awake	Attentive-Inattentive
Placebo									
Mean.....	*112.2*	*6.1*	*5.2*	*5.0*	*4.4*	*5.4*	*5.9*	*4.6*	*5.6*
S.D.....	30.8	1.3	1.6	1.4	1.7	1.5	1.4	1.3	2.0
Caffeine 2 hrs. before adding									
Mean.....	*110.7*	*6.3*	*4.7*	*5.7*	*4.1*	*6.2*	*4.9*	*5.4*	*4.6*
S.D.....	31.2	1.2	1.6	1.4	1.5	1.3	1.4	1.3	1.6
Caffeine 3 hrs. before adding									
Mean.....	*112.2*	*6.2*	*4.8*	*5.3*	*4.7*	*6.1*	*5.5*	*5.0*	*5.2*
S.D.....	29.5	1.1	1.7	1.7	1.8	1.5	1.9	1.8	2.0

See Fig. 1 for the meaning of the subjective rating averages.

It is clear from the data in Table III that the caffeine had no effect on the rate of adding over a fifteen-minute period, regardless of the time of administration. However, some of

the subjective reports indicate a caffeine effect, particularly the reports given after adding.

For example, the average rating on the bored-interested scale after the 15 minutes of addition is 5.4 for the control, and 6.2 for the condition where the caffeine was given two hours before. The critical ratio of the difference between these means is 2.9. The average rating on the peppy-fatigued scale after the 15 minutes of addition is 5.9 for the control, and 4.9 for the condition where the caffeine was given two hours before. The critical ratio of this difference is 4.3. Similarly, the average ratings for the sleepy-wide-awake scale for the 'control' and 'two-hour' conditions are 4.6 and 5.4 respectively, with a critical ratio for the difference of 3.3. Finally, the average ratings on the attentive-inattentive scale are 5.6 and 4.6 with a critical ratio for the difference of 3.0.

Discussion

The results of the main experiment conform to the hypothesis previously developed that certain antihypnotics should allay the development of a bored attitude to a task. The findings of the main experiment also confirm the report of Hoch and Kraepelin (**6**), and of Hollingworth (**7**) that caffeine has a favorable effect on the rate of adding. The fact that the effect of caffeine on the rate of adding is not on the initial performance but on the later performance of a long period, regardless of the time of administration, is of theoretical interest. Such finding makes improbable the view that caffeine has a dynamic effect on specific neural processes immediately involved in adding. A more plausible hypothesis is that the effect of caffeine is on some central process or processes concerned with alertness. In accordance with the latter supposition, it is to be expected that the effect of caffeine on the rate of adding should be manifest where the conditions for the maintenance of the alert state are not favorable. Thus, in the present experiments, the initial alertness adjustments to the task of adding are sufficiently effective to obscure any influence of caffeine. However, as boredom develops, the supporting influence of caffeine on the alertness adjustments to the task may be inferred.

Another hypothesis may integrate the available facts around supposed anti-fatigue properties of caffeine. The two hypotheses are not mutually exclusive. In fact, it would seem very difficult at present to test the validity of one against the other. Without denying the operation of the latter hypothesis, the present writer prefers the former because of the relative simplicity of the operations involved in adding, and the fact that the length of the experimental session can be doubled with little hardship to the subject (**5**). In fact, these reasons contributed to the selection of this type of task for the experiment. It was believed that over a two-hour period the unfavorable changes in rate of adding and feeling tone would be largely due to boredom, rather than to the fatigue of involved neuro-muscular mechanisms.

The foregoing considerations make pertinent the question, "To what extent are the so-called stimulating effects of caffeine on psychological performances a function of two factors: (*a*) the antihypnotic quality of caffeine, (*b*) the opportunities provided by the experimental framework for the development of an attitude of boredom to the task?"

A puzzling byproduct of the present investigation is the finding that the initial effects of caffeine on the subjective reports were negligible when the subjects added for two hours, but were in some instances statistically significant when the addition was altogether 15 minutes long. Whether this difference was intrinsic to the two groups of subjects, or to the length of the period, or to other factors, cannot be determined adequately from the design of the experiments here reported.

Summary and Conclusions

Two experiments are reported. In the first, the main experiment, 29 subjects added pairs of numbers for eight fifteen-minute periods, after each of which they filled out a subjective rating sheet containing four nine-point scales of bored-interested, peppy-fatigued, sleepy-wide-awake, and attentive-inattentive. The experiment was performed under four conditions, (*a*) control, (*b*) 2 grs. of alkaloid caffeine one hour before adding, (*c*) 2 grs. of alkaloid caffeine two hours before adding,

and (*d*) 2 grs. of alkaloid caffeine three hours before adding. Suitable control techniques were used. Under the conditions of the experiment, the following results were obtained:

1. Two grains of alkaloid caffeine administered *one hour* before adding *allayed*:

a. A loss in rate of adding.

b. The development of unfavorable feeling reports on all four subjective rating scales.

2. Two grs. of alkaloid caffeine administered two or three hours before adding had a similar, though lesser, effect.

3. *The effect of the caffeine on the initial rate of addition, or on initial subjective reports, was negligible regardless of the time of its administration.*

In the second and supplementary experiment, 36 subjects added for fifteen minutes and filled out subjective rating scales under three conditions: (*a*) control, (*b*) 2 grs. of caffeine two hours before adding, and (*c*) 2 grs. of caffeine three hours before adding.

Under the conditions of the second experiment:

1. The caffeine had no effect on the rate of addition.

2. The caffeine had an effect on the subjective reports in a more favorable direction, particularly those given immediately after adding.

The significance of the findings is discussed.

(Manuscript received July 9, 1940)

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THE REGION OF THE VISION-FIELD, WITHIN WHICH ARBITRARY REVERSION OF AMBIVALENT FIGURE-GROUND PATTERNS IS POSSIBLE

BY WALTER EHRENSTEIN

p. t. Chicago

In my paper: Untersuchungen über Figur-Grund Fragen, *Z. Psychol.*, 1930, **117**, 339–412, I mentioned on page 375 the fact, observed in previous experiments of mine, that reversions of the well known goblet-faces pattern (from a Greek kylix-vase, first used for psychological purposes by E. Rubin) cannot be brought about arbitrarily and intentionally in peripheral vision, beyond a small visual angle away from the fixation point.

Meanwhile I had opportunity to determine with 10 subjects, most of them assistants and students of the Department of Psychology of Chicago University, the range of central vision, within which arbitrary reversion is possible.

For my experiments I used the original figure in Rubins book on: *Visuell wahrgenommene Figuren*, 1921, which I reproduced photographically. This picture shows in a black quadratic field, of 10.5 cm side-length as ground, a goblet-shaped white infield of 6.6 cm height and 7.8 cm greatest width as figure. If the reversion has taken place and the black part of the picture is figure, one sees two human profiles turned towards each other.

This picture was attached at the wall of a room, which was covered with grey wrapping paper. The vertical and horizontal directions of the vision field, crossing in the center, where the picture was fixed, were marked by a cm-scale with pencil on the wrapping-paper. Every 5th cm in addition was marked by a thumb-tack. The thumb-tacks were varied in color and size, so as to make them look different and thereby more suitable as stopping-points for the eye, which had to approach the picture from the periphery by steps, jumping from one thumb-tack to the other. This proved an advantage over a continuous approach in preliminary experiments, as by an approach in discrete steps the impressions of the observer became clearer and provided more certainty for his judgement on the final stage, when arbitrary reversion became possible.

The distance of the observer from the picture was 228 cm, the observer standing against the opposite wall of the room. The right eye was used exclusively; the left eye was closed. The subjects were shown the meaning of reversion by having the picture arbitrarily change figure and ground in direct vision before the experiments

started. Then they were asked to approach the picture, which was in level with the eye of a medium tall person in one series of observations each from the left, the right, from above, from below, successively fixating thumb-tacks nearer to the picture, until they came to a thumb-tack near enough to realize the intention of making the picture shift regarding figure and ground and of keeping it in the shifted condition against further reversions. As in the goblet-faces picture the goblet has double the chance to be realized as figure (compare my tachistoscopic experiments, by which I determined the tachistoscopic exposure-time necessary for the goblet to be recognized as half the time necessary for the faces to be recognized, Z. *Psychol.*, 117, p. 403), the subjects started with the goblet realized as figure, when they approached the picture from the periphery and tried to achieve a shift by making the faces the figure. Each subject made five observations for each direction of approach; a number of subjects made less than five observations.

The arithmetic mean of the distances in cm for all observations was used as a measure of the maximal distance from the center, which allows reversion. With the aid of the tangent this distance is then expressed by degrees of visual angle.

In a second series of experiments the task was the same as in series 1; the picture however was half as large as in series 1, and the distance of the observer was half the distance as in series 1, *i.e.* 114 cm. The retinal image of the picture was equally large in both series of experiments.

It would take too much space to reproduce here all the results for all our 10 subjects. We give the full record of experimental data only for the subject with the lowest and for the subject with the highest values, *i.e.* the subject for whom the central area, within which arbitrary reversion is possible, is smallest and the subject for whom this area is largest.

We then report the averages from the data obtained for all our 10 subjects.[1]

Results

Our observations show:

1st: An arbitrary reversion of the ambivalent figure-ground pattern known as the goblet-faces picture is not possible in the periphery of the vision-field outside a certain region round the center.

2nd: The region within which arbitrary reversion, obeying the intention of the observer, is possible, is largest in the part of the vision-field which is projected on the temporal side of the retina, *i.e.* the region which lies left of the fixation-point, when the observation is made with the right eye.

3rd: In all other directions the visual angle indicating the outer limits of the region of arbitrary reversibility is almost equal. In our experiments with the smaller arrangement it is

[1] To my subjects, the gentlemen: Bechtold, Coombs, Henry, Petersen, Taylor, Tucker, and Wolfle and the ladies: Busch, Denton, and Gross I wish to express my best thanks for their kind support of this investigation. The observations were made in the Psychological Laboratory of the University of Chicago in fall and winter 1939–40.

SUBJECT: HENRY

Large Arrangement

Arrows Indicating Direction of Approach of the Eye from Periphery	Arithmetic Mean of Necessary Approach in cm	Mean Deviation	Tangent for Greater Distance of 228 cm	Tangent for Smaller Distance of 114 cm	α_2	α_1	$\frac{\tan \alpha_2}{\tan \alpha_1}$
	← 9.8	1.84	0.0430		2° 28′		1.060
	↓ 6.6	0.72	0.0289		1° 39′		1.273
	→ 8.8	1.44	0.0386		2° 13′		0.909
	↑ 6.6	1.28	0.0289		1° 39′		1.398
			Small Arrangement				
	← 5.2	0.64		0.0456		2° 37′	
	↓ 4.2	0.32		0.0368		2° 6′	
	→ 4.0	0.00		0.0351		2° 1′	
	↑ 4.6	0.48		0.0404		2° 19′	

SUBJECT: TAYLOR

Large Arrangement

	←37.0	4.40	0.1623		9° 13′		1.243
	↓ 17.8	2.64	0.0781		4° 28′		1.438
	→21.6	4.72	0.0947		5° 25′		1.445
	↑ 24.6	2.56	0.1079		6° 9′		1.268
			Small Arrangement				
	←23.0	3.60		0.2018		11° 25′	
	↓ 12.8	1.84		0.1123		6° 24′	
	→15.6	1.76		0.1368		7° 47′	
	↑ 15.6	1.52		0.1368		7° 47′	

AVERAGES FOR ALL 10 SUBJECTS

Large Arrangement

	←20.77		0.091		5° 12′		1.3
	↓ 12.48		0.055		3° 11′		1.4
	→12.58		0.055		3° 11′		1.5
	↑ 13.32		0.058		3° 12′		1.5
			Small Arrangement				
	←13.75			0.121		5° 50′	
	↓ 8.78			0.077		4° 26′	
	→ 9.19			0.081		4° 38′	
	↑ 9.85			0.086		4° 55′	

slightly greater in the part of the vision-field above the fixation point, or on the lower half of the retina respectively.

4th: There are considerable individual differences between different subjects, the values of the subject with the largest region of reversibility being almost 4 times greater than the values of the subject with the smallest region of reversibility.

5th: If one compares the values obtained with an observation of a larger picture in greater distance—larger arrangement—with the values obtained with an observation of a picture half as large and observed from a distance half as great—smaller arrangement—one gets considerably higher values for the smaller arrangement, in spite of the congruence of the retinal images in both cases. As in the observation of the Aubert-Förster-Phenomenon, the smaller arrangement is decidedly favored.

6th: This result, which is expressed by the quotient of the tangent of the visual angle obtained for the smaller arrangement as dividend and the tangent of the visual angle of the larger arrangement as divisor, more exactly: by the fact that this quotient reaches values over 1, indicates that the same factors that account for the Aubert-Förster-Phenomenon are in the play in peripheral figure-ground reversion.

7th: Both the Aubert-Förster-Phenomenon and the present observations about reversion of ambivalent figures prove that our vision field is in a varying degree, which is decreasing from the center to the periphery, susceptible to central influences of the higher sphere of personality.

(Manuscript received June 21, 1940)

CORRECTION

In our report in the October issue of this journal [1] we erroneously stated that Anderson and Brandt [2] had required public announcement of goals by the school children who were the subjects in their experiment. Goals were recorded privately, so that their results and ours are confirmatory on groups differing widely in age and educational status.

ERNEST R. HILGARD
EDWARD M. SAIT
G. ANN MAGARET

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